GEOLOGIC PROCESSES AND HISTORY
OF THE
FORT FISHER COASTAL AREA, NORTH CAROLINA

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by

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ABSTRACT

The Fort Fisher area is a complex interaction of nearshore, strandplain, barrier island, and estuarine systems. Relict geologic units have been, and are being, reworked by the coastal processes operating on the nearshore shelf and the strandplain environments to produce the barrier island and estuarine features of the study area. These coastal processes are naturally occurring processes which have been modified by man.

Four mappable relict geologic units occur within the strandplain beach and in the offshore area. Unconsolidated sand units crop out in the eroding bluffs associated with the strandplain beach. Coquina forms platform-like outcrops within the strandplain forebeach. Submerged coquina crops out adjacent to, and south of, the emerged coquina deposits. Relict gravel and coarse sand units also occur in the offshore area. Modern sediments within the foreshore-nearshore consist of fine to very coarse quartz sands mixed with varying amounts of coquina fragments, quartz pebbles, and whole and fragmented shell gravels. Organic-rich mud forms thin blanket-like offshore deposits in depressions at depths of 7.0 m (23 ft) to 9.1 m (30 ft) below Mean Sea Level. The eroding coquina and strandplain bluff sands are an important source of modern sediment to the Fort Fisher foreshore-nearshore system.

A continuum of erosional processes occur along the Fort

Fisher strandplain shoreline. Coquina outcrops on the north side of Fort Fisher produce a disequilibrium condition within the forebeach resulting in increased shoreline recession along the beaches adjacent to the rock outcrops. The strandplain bluff is undercut and eroded by wave swash and gullied by rainfall runoff. When these sediments are moved offshore during storms, the extensive coquina outcrops act as a barrier which prevents the landward transport of the sediments during low energy periods. The onshore rocks also extend seaward into the nearshore and act as low groins; this produces a net sediment loss to the adjacent downdrift southern beach. As a result of this sediment deficiency, the adjacent beach develops a steep forebeach profile associated with rapidly eroding bluffs. This results in the development of a rapidly receding cove structure. The upper portions of the coquina are continuously eroded by wave impact and abrasion, ultimately forming submerged "reefs" as the shoreline receeds.

The southern end of the study area is characterized by the Fort Fisher barrier island system. The barrier is dominated by spit extension processes associated with the rapid southward migrations of New Inlet that began in response to the construction of the New Inlet Dam in 1881. Inlet development within the northern portion of the barrier and subsequent southward migration has been an important reoccurring process of the barrier beach.

Since 1852, the Fort Fisher shoreline has experienced both dramatic accretion and erosion. Accretion occurred from

1852 to 1865. This was probably related to the southward migration of New Inlet. Erosion occurred during the period 1865 to 1923 as the former inlet dominated system adjusted to a new energy regime created by the construction of the New Inlet Dam. Since 1923, the inordinate erosion of the Fort Fisher Historic Site shoreline has occurred in response to the sequential exposure of coquina outcrops within the strandplain forebeach.

The erosional processes related to the coquina will probably continue to operate in the future. Shoreline recession rates will probably accelerate northward along the northern strandplain beach as new portions of the linear rock unit become exposed. The entire strandplain beach, coquina, and barrier island system must be considered as a totally interacting unit in planning any future shoreline protection measures at Fort Fisher.

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INTRODUCTION

The Fort Fisher shoreline is unique within the North Carolina coastal system; sandy coquina crops out within the forebeach area of the strandplain beach. In spite of the presence of the rock outcrops, the Fort Fisher shoreline has experienced an average erosion rate of 3.3 m/yr since 1865, for a total recession of 370 m. This rate is considerably higher than the average of 1 to 2 m/yr for much of the rest of the North Carolina coast. This study has found that the occurrence of coquina outcrops within the rapidly eroding strandplain shoreline is not fortuitous. Thus, the primary objective of this study is to determine the relationship of the geology of the Fort Fisher area to the coastal processes that have occurred since 1852.

STUDY AREA

The Fort Fisher area is located in southern New Hanover County, North Carolina (Figure 1), an area locally referred to as Federal Point. The study area is located at the southern end of a mainland peninsula formed by the convergence of the southward-flowing Cape Fear River and the Atlantic Ocean. The study area, as indicated in Figure 1, includes the Fort Fisher beach and the directly adjacent upland areas and extends seaward about 1 km including approximately 2.3 km of ocean shoreline.

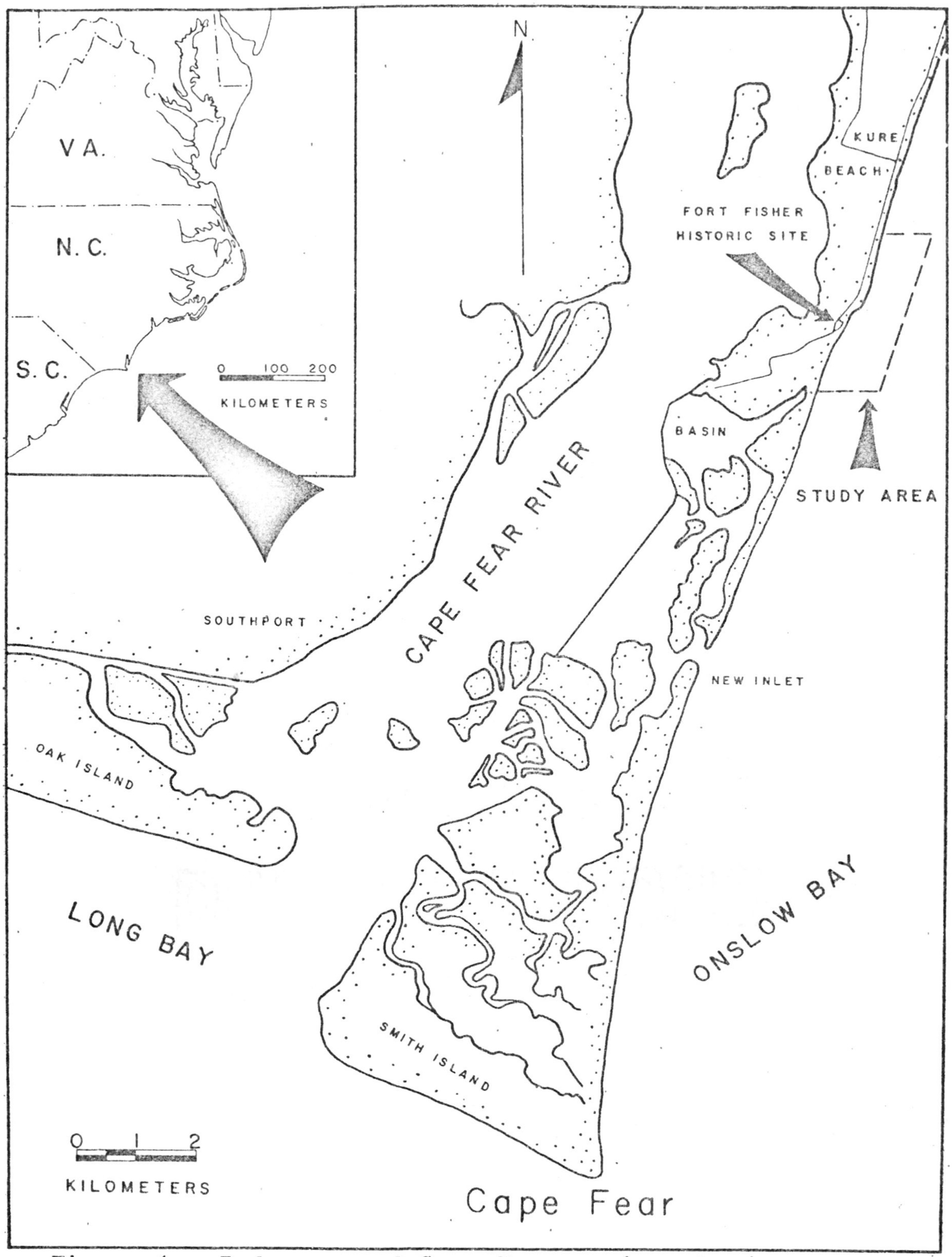

Figure 1. Index map of Cape Fear region showing area studied.

CULTURAL HISTORY OF THE FORT FISHER AREA

Since the 1860's, man has played an important role in the coastal processes that have occurred within the study area. Many of the present coastal processes can be directly attributed to man's interference with the once natural Fort Fisher coastal system. Consequently, a brief survey of man's history and former land use of the area is in order.

Fort Fisher has been important to the nation's coastal defense since the late 1700's. New Inlet, which initially opened in 1761, provided a second entrance to the Cape Fear River (Figure 2). The main channel of New Inlet was deep, yet local citizens kept this fact secret to discourage pirateering (Waddel, 1909).

With the advent of the Civil War, Fort Fisher became increasingly important in the defense of the lower Cape Fear River. In 1861, construction of an earthwork fortification was begun on the northern shore of New Inlet. By 1862, major construction was underway with the help of 1,000 men, 500 of which were slaves (Mordecai and Worthington, 1977). When finished, the fort was L-shaped running east-west from the Cape Fear River to the ocean, then turning southward along the ocean shoreline (Figure 2). The fortifications consisted of huge earthen mounds which were connected by fences. These mounds served as both gun batteries and bombproofs (U. S. Army Corps of Engineers, 1974). Fort Buchanan, a similar

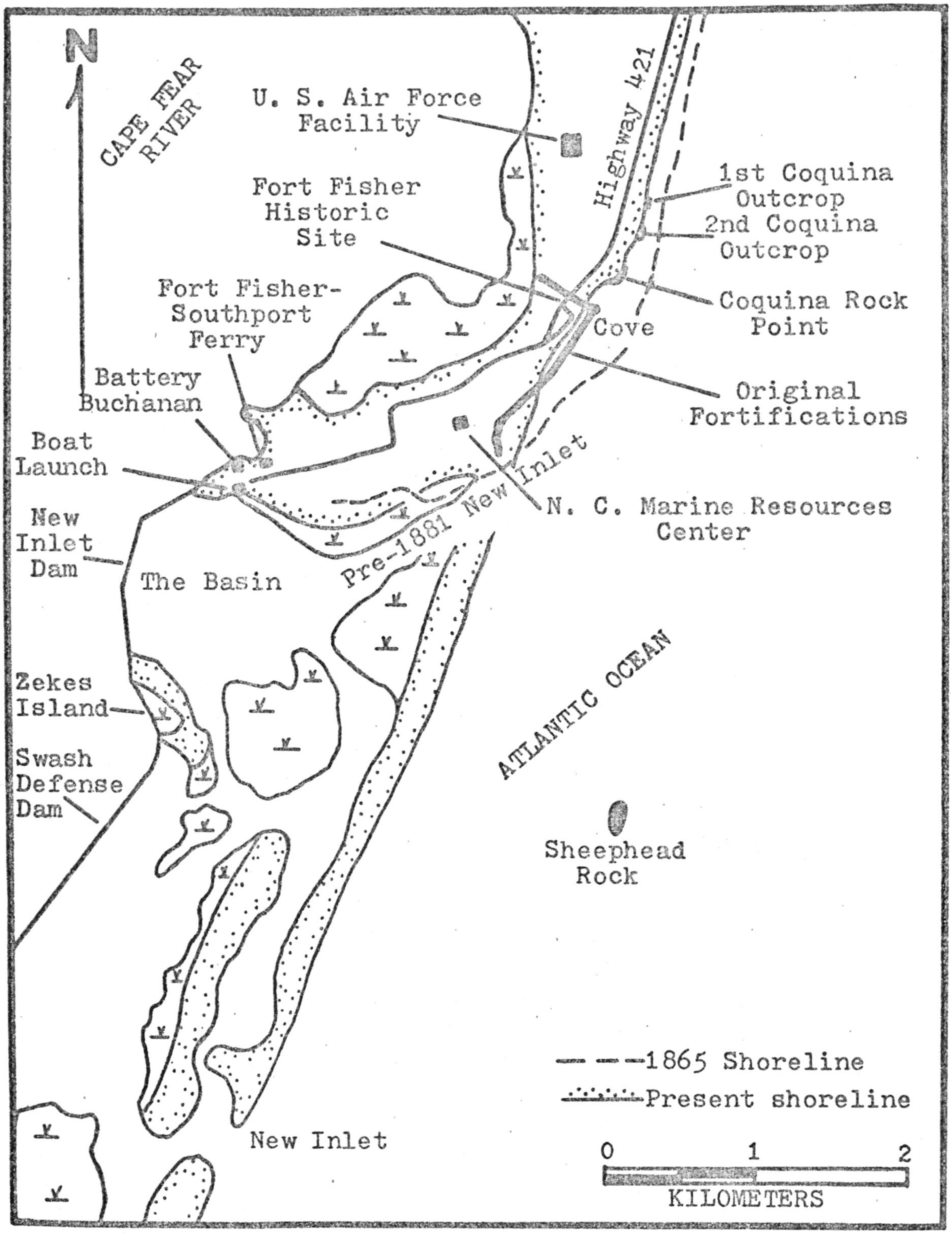

Figure 2. Location map of Fort Fisher area.

mound battery, protected the western end of New Inlet (Figure 2). Prior to late 1864, Confederate blockade runners were able to sail quickly through the Union naval blockade offshore of Fort Fisher and into the New Inlet channel under the protective guns of the fort. Realizing the Port of Wilmington was the Confederacy's last lifeline for supplies, the Union mounted an immense land-sea invasion during December, 1864 and January, 1865 (U. S. Army Corps of Engineers, 1974). The fort was finally taken on January 15 and, by February 21, the Port of Wilmington was occupied by Federal troops. The ocean-front fortifications have since eroded and only a few earthworks remain in the Historic Site area. Numerous Civil War shipwrecks lie in the waters offshore of Fort Fisher.

During the 1870's, the New Inlet Dam was constructed with the purpose of closing New Inlet and preventing further shoaling of the main Cape Fear River channel (U. S. Army Corps of Engineers, 1931). This closure of New Inlet has had more effect on the Fort Fisher coastal system than any other of man's activities. The inlet was once a major outlet of the Cape Fear River with a main inlet channel depth of 5.5m (18 ft) to 6.1 m (20 ft) which allowed considerable amounts of river water to flow seaward through the inlet. The fairly constant hydraulic pressure created by the Cape Fear River caused New Inlet to remain relatively stationary. During the early 1800's, an extensive floodtide delta began to shoal across the main river channel. In order to prevent further shoaling of the river, steps were taken to close New Inlet. In 1852, a fence dam, or cribbing, was built out into the inlet in the vicinity of Zekes Island (Figure 2). This structure proved to be ineffective and in 1875 construction of the New Inlet Dam was begun (U. S. Army Corps of Engineers, 1931). The dam, which was completed in 1881, was approximately 1.6 km long, 30.5 m wide at its base, and 9.1 m high (Cleary and Hosier, 1976). It consists of limestone boulders and smaller blocks of granite and basalt capped by concrete. The dam effectively stopped the flow of river water through the inlet and is still an effective structure today.

During World War II, Fort Fisher served as a military installation used to protect the offshore areas from submarine attack (Mordecai and Worthington, 1977). An experimental radar tower, artillery targets, ammunition bunkers, and an abandoned airstrip are remaining remnants of the World War II period. After World War II, Fort Fisher became part of the buffer zone of the Sunny Point Ammunition Loading Terminal located on the west bank of the Cape Fear River. Most of the military buildings have since been removed. In the early 1950's, the Fort Fisher Air Force Station was established as a radar defense installation.

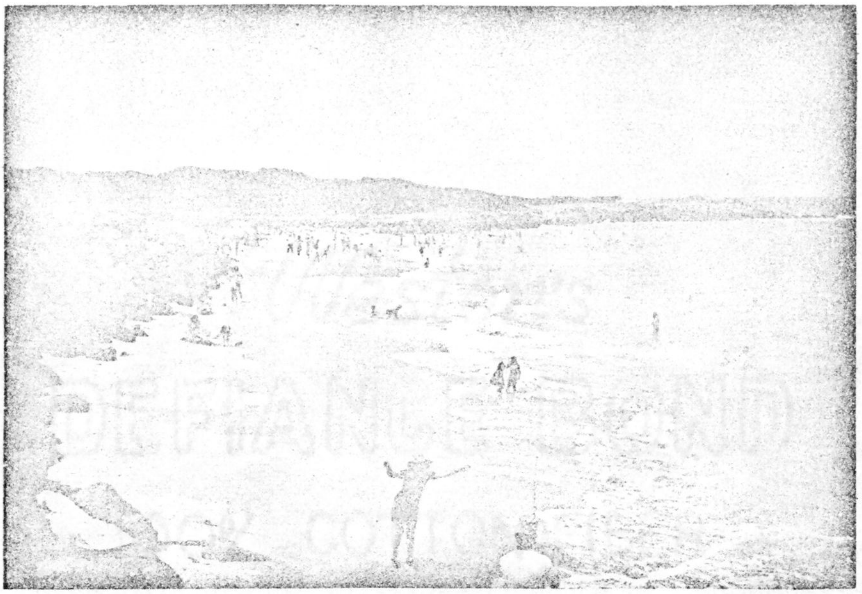

Figure 3. View, directed north, of the Fort Fisher Historic Site beach on a typical summer day. Coquina rock point is in the far right of the photograph.

PRESENT USE OF THE STUDY AREA

The majority of the study area is owned and supervised by the State of North Carolina. The remains of Fort Fisher are under the supervision of the Department of Archives and History which also maintains the Fort Fisher Visitor Center-Museum and the adjacent picnic area.

Within the past decade, North Carolina has experienced an explosion in all types of coastal recreation. The Fort Fisher area is no exception, as beach-related uses have increased substantially (Figure 3). The availability of public parking and beach access has been an important factor in the increased use of this area. The uniqueness of the beach area itself is also a factor. The sand bluffs fronting the shoreline and the adjacent maritime thicket provide a scenic vista. The coquina outcrops provide for excellent exploring at low tide and are a habitat for various sport fish. The outcrops also produce excellent wave conditions for surfing. The offshore area is trawled extensively by commercial shrimpers. Submerged coquina outcrops, located southeast of the Fort Fisher Historic Site, provide excellent fishing for gray trout and sheephead. These outcrops are presently being considered for inclusion in an underwater state park or natural area.

At the present erosion rate, Highway 421 and the entire Fort Fisher Historic Site will be eroded away by about 1998 (Mordecai and Worthington, 1977). A sound erosion control program must be implemented if this area is to be preserved in its present state. Hopefully, this study will supply some of the basic geologic information necessary for the development of such a program.

OBJECTIVES OF STUDY

The objectives of this study are:

1) to delineate and define the relict and modern geologic units within the Fort Fisher coastal system,
2) to study the relationship of the relict geologic units to the modern sediments within the present Fort Fisher coastal system,
3) to better understand the relationship of Fort Fisher

geology to the coastal processes, as modified by man, from 1852 to the present,

4) to provide insight into the future shoreline processes within the Fort Fisher coastal system.

METHODS OF STUDY

Field Methods

A series of three contiguous base maps were made at a scale of 1:1,200 utilizing a plane table and alidade (Figure 4). Features mapped included berms, bluffs, dunelines, vegetation, rock outcrops, and roads. The maps were also used for locating the onshore sediment and rock samples, stratigraphic sections, and offshore profile traverses. Stratigraphic sections of the coquina and sand units exposed within the strandplain bluffs were measured, described, and sampled.

A grid of eight east-west offshore traverses was established (Figure 4). The traverses were located in conjuction with previously mapped points on the beach. A Ray-Jefferson straight line depth recorder was used to record offshore bathymetry along each of the eight traverses. Each profile was run from the breaker zone seaward to an estimated distance of 1 km from shore. Four hand grab samples were taken by SCUBA divers along each traverse. A system of crossed ranges and triangulation, shot by two surveying transit parties on the beach, was used to accurately locate the traverse profiles and bottom samples. The SCUBA divers described the bottom

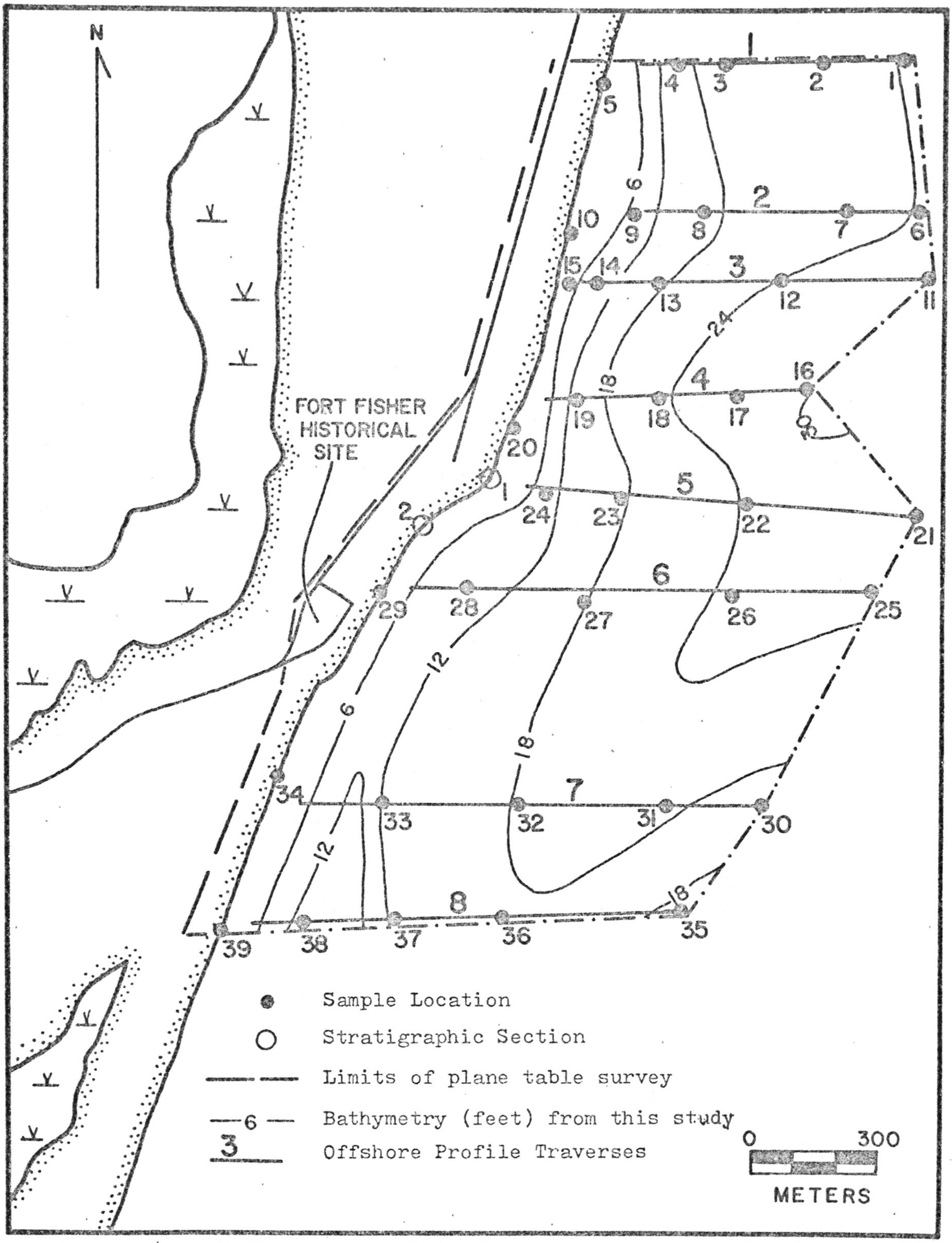

Figure 4. Offshore profile traverse and sample location map. Bathymetry contoured from continuous depth profiles recorded along each offshore traverse.

characteristics and bedforms when visibility allowed. The offshore area was sampled on August 23 and 24, 1976.

Laboratory Methods

Unconsolidated sand samples were dried and split into 30 to 100 gm samples. During an initial investigation, all sand samples were described using a binocular microscope. Median grain size, sorting, composition by volume, and color were estimated. All offshore and selected representative onshore sand samples were sieved and analyzed using Folk's (1968) techniques. Percentages of shell and coquina fragments in each sample were estimated.

General clay composition of one mud sample was analyzed using X-ray diffraction analysis methods. The approximate percentage of organic material in one mud sample was determined with a low temperature asher. Coquina samples were described using a binocular microscope. Seven representative samples were thin sectioned and studied using a polarizing microscope. Two coquina samples were subjected to dissolution in a HCl bath. Insoluble versus initial sample weights were recorded.

Treatment of Sieve Analysis Data

Sieve weights were converted to percentages and plotted as cumulative curves on probability paper. The Graphic Mean and Inclusive Graphic Standard Deviation (Folk, 1968) were calculated for each sample. Folk's (1968) grain size and sorting nomenclature were used to describe each sample.

Terms used to describe shell content by weight are 1) 0.1 to 3.0%, slightly shelly, 2) 3.1 to 10%, moderately shelly, and 3) greater than 10%, shelly.

Historical Shoreline Study

Shoreline locations were compiled from hydrographic surveys, aerial photographs, topographic maps, and previous publications. A Map-O-Graph enlarger was used to obtain a common map scale for all the sources. Sources of shoreline locations and historical bathymetry in the study area are:

1) 1852 - U. S. Coast and Geodetic Hydrographic Survey No. H-372, Hydrographic Index No. 72B.

2) 1858 - U. S. Army Corps of Engineers, Plate II (1931) and U. S. Coast and Geodetic Hydrographic Survey No. H-643, Hydrographic Index No. 72D.

3) 1865 - U. S. Army Corps of Engineers, Plate II (1931) and U. S. Coast and Geodetic Hydrographic Survey No. H-875, Hydrographic Index No. 72D.

4) 1872 - U. S. Coast and Geodetic Hydrographic Survey No. H-1134, Hydrographic Index No. 72E.

5) 1877 - U. S. Army Corps of Engineers, Plate III (1931).

6) 1882 - U. S. Army Corps of Engineers, Plate III (1931).

7) 1884 - U. S. Army Corps of Engineers, Plate III (1931).

8) 1887 - U. S. Army Corps of Engineers, Plate III (1931).

9) 1895 - U. S. Army Corps of Engineers, Plate IV (1931).

10) 1897 - U. S. Army Corps of Engineers, Plate IV (1931).

11) 1901 - U. S. Army Corps of Engineers, Plate IV (1931).

12) 1923 - U. S. Coast and Geodetic Hydrographic Survey No. H-4312a, Hydrographic Index No. 72H.

13) 1931 - U. S. Army Corps of Engineers, Plate VI (1931).

14) 1942 - Snow Marsh Quadrangle, U. S. Army Map Service, Series V842, Sheet 5451 IV NW.

15) 1949 - U. S. Department of Agriculture, Soil Conservation Service aerial photographs, Series AOH AOQ, Nos. 1F-3, 1F-4, and 1F-65, Burgaw, North Carolina.

16) 1975 - Kure Beach, North Carolina Quadrangle Orthophotograph, Advanced Print, U. S. Geological Survey, 7.5 minute series.

Use of Metric and English Units of Measure

All hydrographic surveys used in this study have bottom contours expressed in feet, thus all offshore depths have been presented in feet. All other linear measurements are presented in metric units which have been converted from English measurements used in the field.

DESCRIPTION OF THE FORT FISHER REGION

The study area is located on the Coastal Plain of south-eastern North Carolina (Figure 1). The region has a humid temperate climate. Coastal plain relief is low, producing slow, sluggish streams and rivers. The Cape Fear River is the only major stream in the study area region. It is a Piedmont stream with a large drainage area of 23,696 km^2 (Louder, 1963). The lower Cape Fear River is dredged periodically to depths of 9.1 m (30 ft) to 12.2 m (40 ft) to provide ocean access to the Port of Wilmington. Topography within the onshore study area generally varies from sea level to approximately 6 meters above sea level.

REGIONAL GEOLOGIC SETTING

The surface sediments of the Coastal Plain of North Carolina consist of a thin blanket of marine and estuarine sands and clays that were deposited during higher Pleistocene sea levels. These Pleistocene deposits occur in a series of terraces and scarps related to previous shoreline locations. Fort Fisher is located approximately 15 km east of the Suffolk Scarp (Figure 5) which is believed to represent the shoreline location of the last major high stand of sea level (Winker and Howard, 1977).

The Pleistocene deposits generally overlie a thick wedge of Cretaceous and Tertiary terrigenous and carbonate deposits.

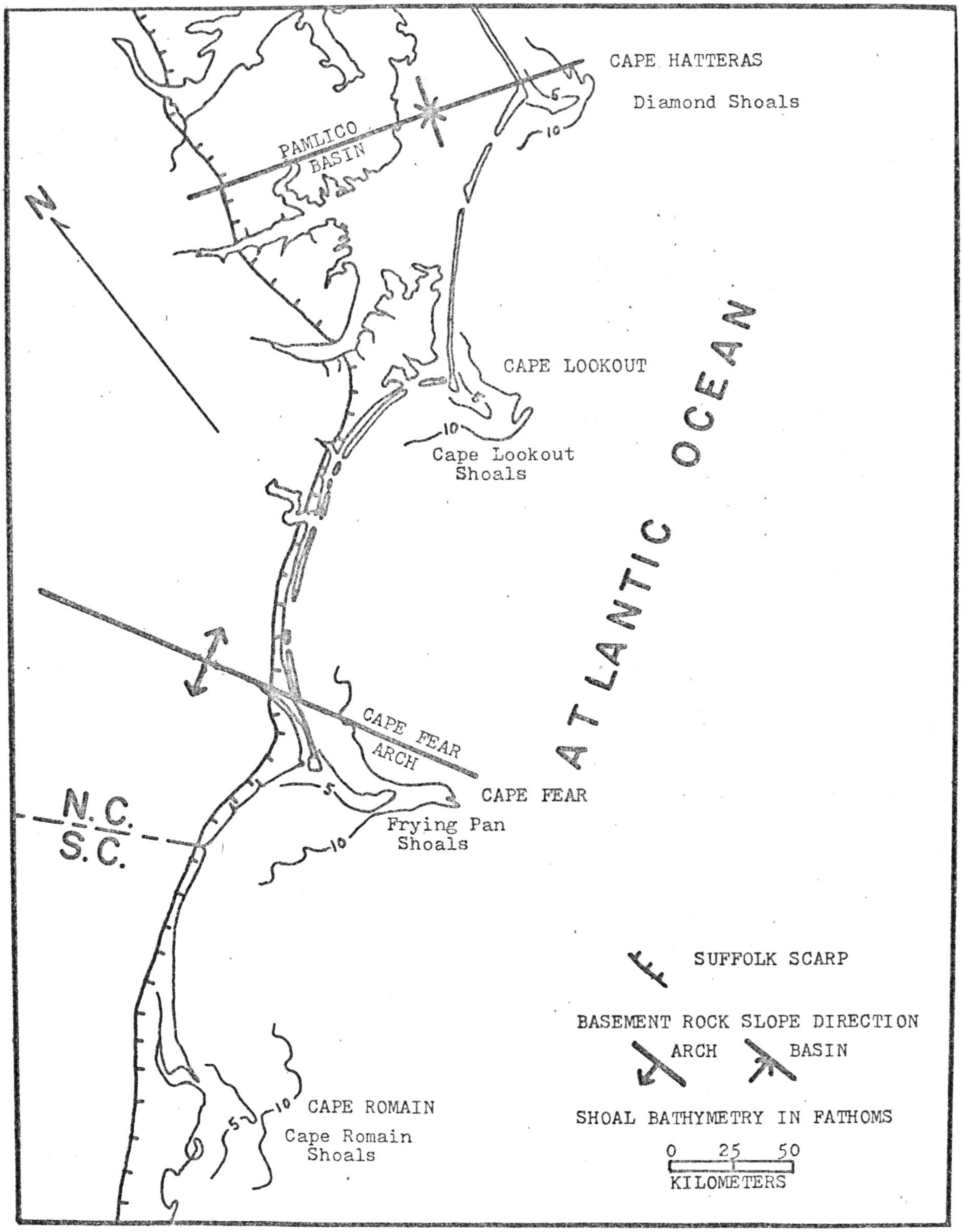

Figure 5. Map of North and South Carolina cape-shoal structures and associated structural and geomorphic features (Modified from Hoyt and Henry, 1971).

This seaward thickening sequence of Coastal Plain sediments overlies crystalline basement rock. Data from a well at Fort Fisher (Brown et al, 1972) indicates the following section:

1) 18.3 m of undifferentiated surficial Post-Miocene medium sands,
2) 14 m of Oligocene sandy algal and shell limestone,
3) 33.5 m of Eocene fossiliferous mold and cast limestone,
4) 412 m of Cretaceous sands and muds,
5) crystalline basement rock.

Fort Fisher is located on the south limb of the Cape Fear Arch (Figure 5). The Cape Fear Arch is a ridge of structurally high basement rock which trends northwest-southeast. The basement depth at Fort Fisher is 471 m (Brown et al, 1972) in comparison to the depth of basement at Cape Hatteras which is approximately 3,050 m. Balazs (1974) reports that a portion of the Cape Fear Arch known as the Southport Rise has been elevated at a rate of 6.5 mm/yr from 1932 to 1963. The town of Southport (approximately 16 km southwest of Fort Fisher) is the center of this land rise anomaly. This structure was periodically active during the Tertiary as suggested by the offlap character and distribution of the various Tertiary stratigraphic units (Riggs, personal communication). The origin and structural mechanics of the Cape Fear Arch, as well as the role that this tectonic uplift plays in the Fort Fisher coastal system, are unknown.

The Fort Fisher coastal system is located on the northern flank of the Cape Fear Cuspate Foreland System. Cape Fear is one of a series of such cuspate forelands along the coast of the Carolinas between Cape Hatteras, North Carolina and Cape Romain, South Carolina (Figure 5). Elongate shoals extend seaward from these capes; Frying Pan Shoals extends seaward approximately 50 km off Cape Fear (Figure 5). Barrier islands extend north and southwest off the Cape. Hoyt and Henry (1971) discuss the theories for the development of cuspate forelands. It is generally accepted that the capes have maintained their basic positions and morphologies throughout the Pleistocene Epoch by migrating landward or seaward in response to transgressive and regressive changes in sea level respectively.

HYDROGRAPHIC SETTING

Winds

Data from the U. S. Naval Weather Service Command (1970) for the Hatteras area includes conditions for the entire North Carolina offshore area during the period 1963 to 1968. Table 1 indicates that the winds may be grouped in three patterns. North and northeast winds blow 31.8% of the time, producing 0.9 to 1.8 m wave heights approximately 50% of the time. East, southeast, and south winds blow 29.9% of the time, producing 0.3 to 1.2 m wave heights 60% of the time. Southwest, west, and northwest winds predominate and produce

WIND DIRECTION	FREQ.	SEA HEIGHTS PRODUCED	FREQ. OF SEA HEIGHTS PRODUCED
North	19.8%	0.9 to 1.8 m	50%
Northeast	12.0%	0.9 to 1.8 m	47%
East	7.8%	0.3 to 1.2 m	57%
Southeast	6.4%	0.3 to 1.2 m	61%
South	15.7%	0.3 to 1.2 m	60%
Southwest	15.7%	0.9 to 1.8 m	53%
West	11.5%	0.9 to 1.8 m	47%
Northwest	11.2%	0.9 to 1.8 m	47%

Table 1. Wind direction frequencies and dominant sea height produced by each wind direction. For example, northerly winds blow 19.8% of the time, producing 0.9 to 1.8 m sea heights 50% of the time the wind is blowing from the north. Data for the Hatteras area is from the U. S. Naval Weather Service Command (1970) for the period 1963 to 1968.

0.9 to 1.8 m waves; however, these winds and waves do not substantially affect the Fort Fisher shoreline due to its east facing orientation. Consequently, conditions are generally calm in the nearshore waters during southwest, west, and northwest winds. Often, northwest winds result from weather systems which simultaneously produce northeastly swells which greatly increase the nearshore energy conditions. Wind speed in the study area is generally less than 20 knots 80% of the time (Table 2). These wind conditions, when combined with the orientation of the Fort Fisher shoreline, result in a dominant north to south littoral current.

Waves

The wave data in Table 3 was collected by ships at sea and therefore is not totally indicative of the waves which affect the Fort Fisher shoreline. The data does, however, offer some insight into the general wave climate of the study area. Waves of 1.2 m or less occur 58.7% of the time with periods of 6 seconds or less. Waves greater than 1.2 m in height occur 41.3% of the time. This latter figure reflects the influence of deeper water and includes strong southwest winds which do not directly affect the Fort Fisher nearshore system. Wave height and period data collected at Frying Pan Light Tower, 61 km southeast of the study area, indicates waves up to 1.2 m in height occur 71% of the time (U. S. Army Corps of Engineers, 1974). Ninety-four percent of these waves had periods of 5 to 10 seconds.

WIND SPEED	FREQ.
Less than 4 knots	2%
4 to 10 knots	26%
11 to 21 knots	51%
Greater than 21 knots	21%

Table 2. Frequency of wind speeds for the Hatteras area during the period 1963 to 1968 (U. S. Naval Weather Service Command, 1970).

WAVE HEIGHT	FREQ.
Less than 0.3 m	6.3%
0.3 to 0.6 m	23.2%
0.9 to 1.2 m	29.2%
1.5 to 1.8 m	19.3%
Greater than 1.8 m	21.9%

Table 3. Frequency of wave heights for the Hatteras area during the period 1963 to 1968 (U. S. Naval Weather Service Command, 1970).

The average wave climate at Fort Fisher can best be described by waves 0.3 to 1.2 m in height with 5 to 10 second periods. Waves may range up to 5 m in height during tropical cyclones or hurricanes. Extratropical storms or "northeasters" produce waves 1.2 to 2.4 m in height continuing over a period of days.

Tides

The diurnal astronomical tides have a mean range in the study area of 1.2 m, while the spring tide range is 1.4 m (U. S. Army Corps of Engineers, 1974). Storm tides, resulting from the landward translation of ocean waters by onshore winds, play an important role in the erosional processes at Fort Fisher. The erosional effect of a storm tide is enhanced when it occurs at the same time as the normal astronomical high tide. Storm tides may range from centimeters to meters above the normal tide level. The highest recorded storm tide at Fort Fisher was 3.2 m above mean sea level during Hurricane Hazel, October 15, 1955 (U. S. Army Corps of Engineers, 1974).

Storms

Storms, in the form of hurricanes and extratropical cyclones, are the major forces producing dramatic changes in the shoreline of the study area. The U. S. Army Corps of Engineers (1974) report that during the period 1700 to 1964, 122 hurricanes directly and indirectly affected the Fort

Fisher shoreline resulting in a yearly average of 2.1 hurricanes per year. The effect of each hurricane ranged from minimal to catastrophic. The impact of any one hurricane is dependent upon many factors including the following: storm surge, direction of forward motion, pattern and magnitude of astronomical tides, and storm duration (Riggs, 1976).

Extratropical storms, locally termed "northeasters", occur generally from October to May. These storms consist of strong northeast winds which may blow continuously for 3 or more days. Dramatic shoreline changes may result from these extended periods of wave attack. Significant shoreline erosion has occurred at Fort Fisher as the result of extratropical storms (Figures 6 and 7).

ENVIRONMENTAL GEOLOGIC SETTING

The Fort Fisher area is a complex interaction of nearshore, strandplain, barrier island, and estuarine systems. Relict geologic units which comprise the southern end of the Cape Fear Peninsula have been, and are being, reworked by the coastal processes operating on the nearshore shelf and the strandplain beach environments to produce the barrier island and estuarine features located south of the study area.

The shoreline within the immediate study area is characterized as a strandplain beach. The most distinctive feature of the strandplain is the erosional bluff which

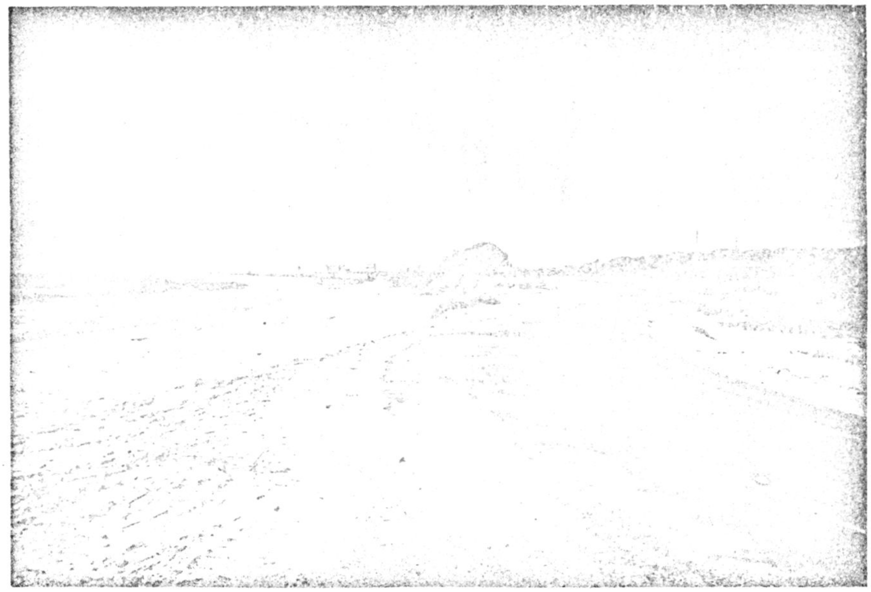

Figure 6. View, directed south, of the Fort Fisher Historic Site shoreline, cove area, and location of Highway 421 prior to an extratropical winter storm in 1946 (Photograph from U. S. Army Corps of Engineers, 1974).

Figure 7. View, directed south, of severe beach and bluff erosion of the Fort Fisher shoreline resulting from an extratropical storm during the winter of 1946 (Photograph from U. S. Army Corps of Engineers, 1974).

consists of relict granular sand deposits. A modern barrier island beach extends from the strandplain beach southward and was formed by spit extension as New Inlet migrated southward. The processes occurring along the barrier beach at Fort Fisher are similar to those occurring along the Outer Banks of North Carolina. These processes include the seaward transport of forebeach and backbeach sediment during storms, and landward sediment transport during low energy conditions. During the higher energy storm situations, erosion of forebeach sediment is accompanied by overwash deposition along the sound or estuarine side of the barrier island. In this manner, the barrier island is able to maintain its identity as it migrates landward.

New Inlet, located at the southern end of the Fort Fisher barrier (Figure 2), consists of a main inlet channel, numerous inlet channel shoals, a poorly developed floodtide delta, and a broad ebbtide delta. The location and extent of these features changes continuously. Approximately 7.8 km^2 of shallow bay and marsh are under the direct tidal influence of New Inlet.

The estuarine system, which is located west of the barrier, is the most extensive system within the study area region and consists of the bay, tidal channels, tidal shoals, tidal sand flats, sand beaches, *Spartina* marsh, and *Juncus* marsh. These environments comprise a highly productive ecological system. The bay, locally referred to as "The Basin", is separated from the Cape Fear River by the New Inlet Dam and consists of a complex of broad, shallow estuaries. The bay is connected to New Inlet and the ocean by a maze of sinuous tidal channels. Spartina alterniflora marsh is the dominant low marsh within the estuarine system and occurs as both marsh islands and as fringing marsh. The Juncus roemerianus marsh represents the high marsh which is located landward and slightly higher in elevation than the Spartina marsh.

The upland areas in the Fort Fisher vicinity are characterized by live oak (Quercus virgininiana) and yaupon (Ilex vomitoria)thickets in areas subject to salt spray winds and live oak and longleaf pine (Pinus palustris) forests further landward.

C O A S T A L   G E O L O G Y

Sampling in the study area indicates the presence of both relict and modern sediment and rock units. Figure 8 shows the distribution of relict and modern sediment and rock units along the beach and nearshore coastal area adjacent to Fort Fisher. Figure 9 illustrates the general relationship of the relict units exposed in the strandplain bluffs to the modern units of the shoreface and inner continental shelf.

RELICT UNITS

The relict units which crop out in the strandplain beach (Figure 10) include the coquina shelf or platform and the sand units exposed within the eroding bluffs. A generalized stratigraphic section of the relict units is illustrated in Figure 11. Relict units which occur in the offshore area are not included in the stratigraphic section. The stratigraphic relationship of onshore and offshore relict units is uncertain.

Coquina

The term "coquina" has been used to describe quite different rock lithologies and should probably be abandoned. Coquina, as used by Pettijohn (1975), refers to cemented, coarse shelly debris. Folk's (1968) terms, calcirudite and calcarenite, are only applicable if the rock consists of a

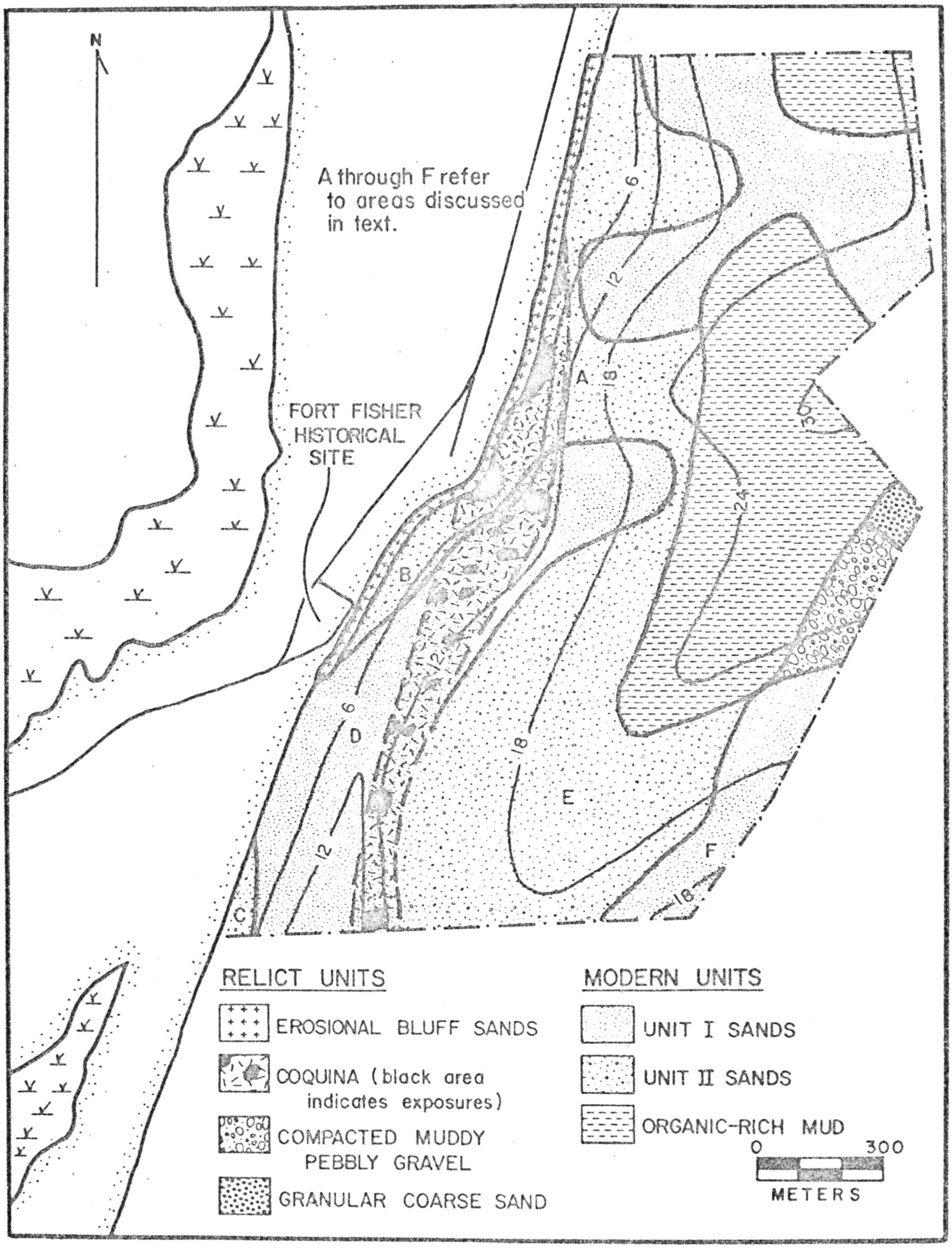

Figure 8. Geologic map of modern and relict sediment and rock units in the study area.

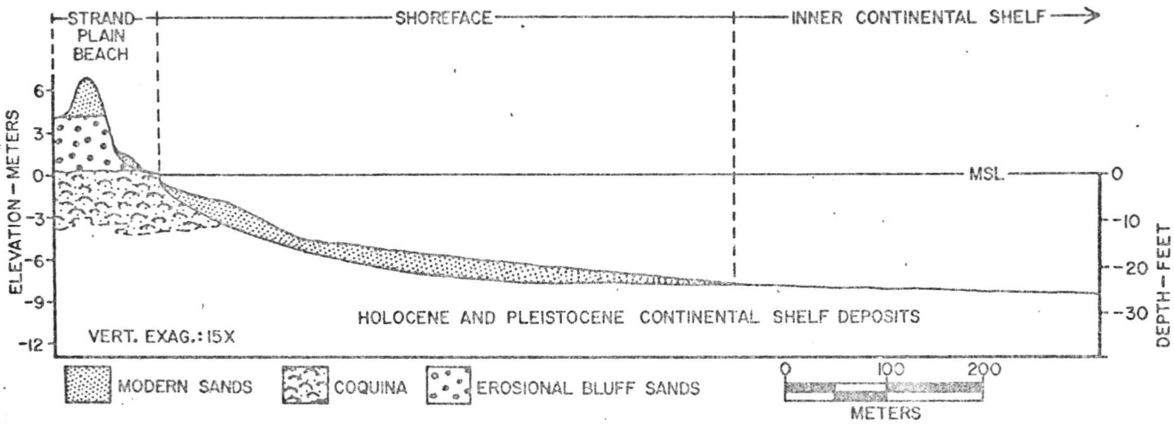

Figure 9. Generalized cross section of the Fort Fisher strandplain and nearshore system.

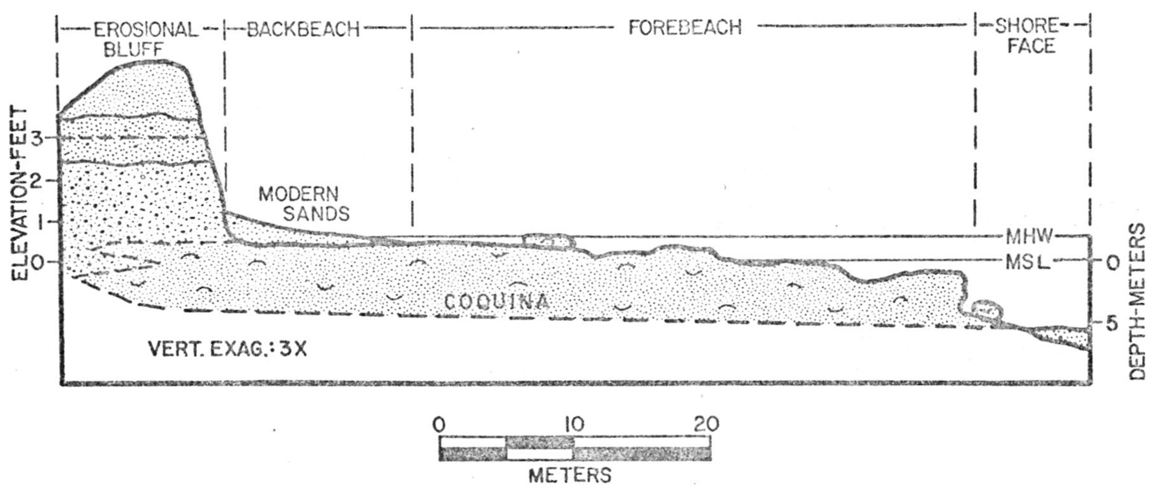

Figure 10. Generalized cross section of the Fort Fisher strandplain beach.

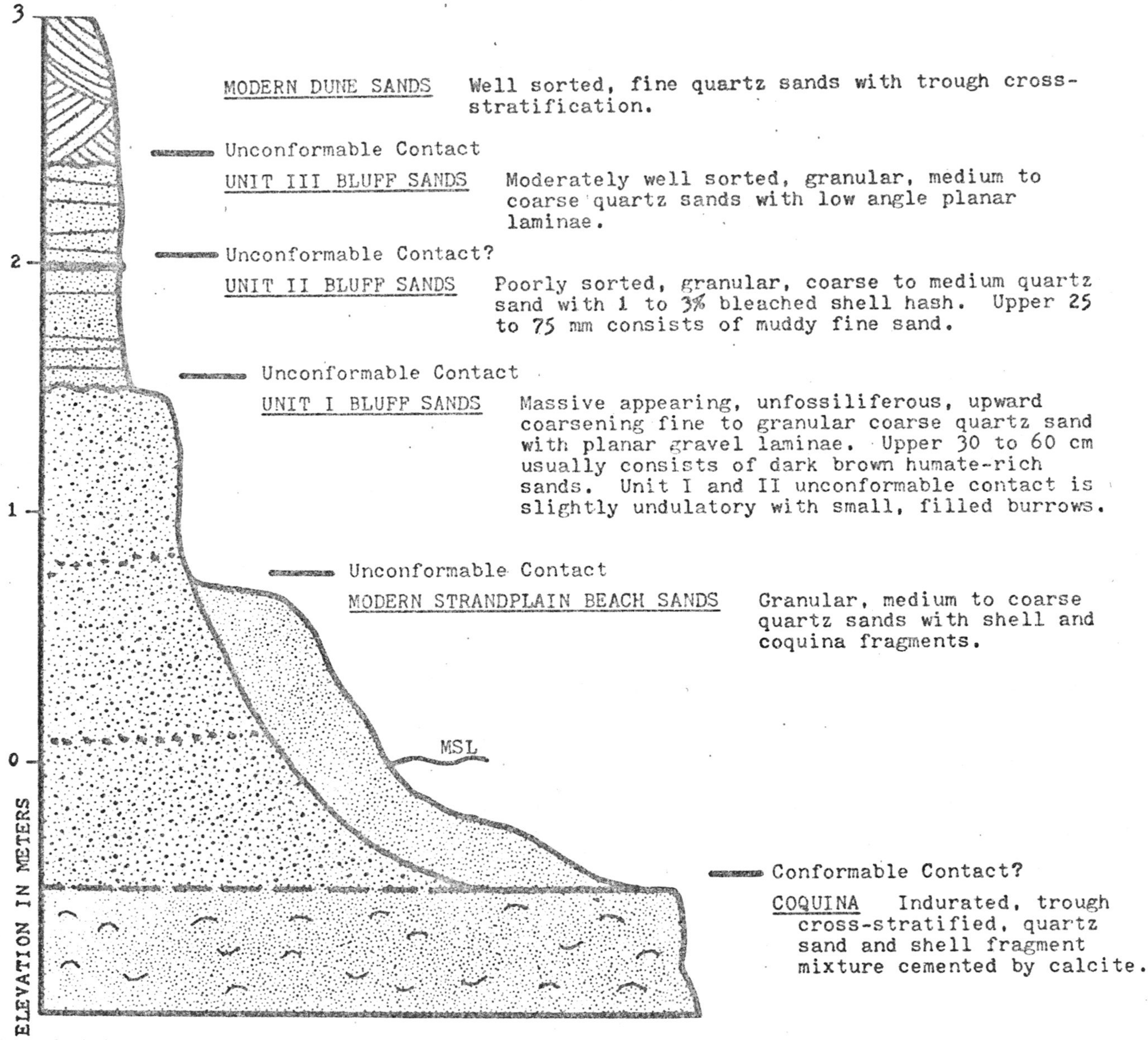

Figure 11. Generalized stratigraphic section of relict sediment and rock units exposed within the Fort Fisher strandplain beach.

carbonate fraction which is greater than 50%. The term "beachrock" is also used frequently to denote coquina-type rocks. Beachrock, however, is a genetic term which refers to beach sediments which are cemented by calcium carbonate in the intertidal zone (Stoddart and Cain, 1965). The lack of a well-defined, purely descriptive term to adequately describe the rock in this study is evident. Also, a complete petrographic study of coquina-type rocks is beyond the scope of this study. Thus, for lack of a better term, coquina is used in this study to refer to a porous mixture of shell debris and quartz sand cemented by calcium carbonate.

The onshore coquina rock is exposed in three outcrops (Figures 2 and 8). These outcrops form a platform which extends from the erosional bluff or backbeach seaward to the low tide level where an actively eroding 0.9 to 1.2 m high ledge occurs (Figure 10). Abraded coquina blocks, derived from the upper outcrop surface and the eroding ledge, are strewn across the rock platform. The submerged coquina rock is exposed as a rock bottom adjacent to the onshore rock and as "reefs" in the nearshore south of the onshore rocks.

The coquina exposed onshore and offshore within the study area are identical in lithology. The rock is generally grayish orange (10 YR 7/4) in color and is well indurated. The weathered surface usually has a rough and knobby texture. Porosity measurements indicate an approximate average of 60%. Insoluble fractions of two representative samples were 59%

and 66% by weight. The insoluble residue in both samples consisted of moderately sorted, subrounded to rounded, medium quartz sand. Rounded quartz pebbles and cobbles are common in the outcrops. Trace amounts (less than 0.01%) of heavy minerals and phosphate grains are present.

Soluble material consists primarily of abraded and rounded shell fragments 1 to 2 mm in diameter and calcite cement. The shell fragments are bleached, white, chalky in texture, and are mostly oriented with their long axes parallel to the bedding plane (Figure 12). Megafossils in the coquina at Fort Fisher include *Fulgur carica*, *Crassostrea virginica*, *Mercenaria mercenaria*, and *Rangia cuneata* as reported by Stephenson (1912). Richards (1950) reports the additional occurrence of *Noetia ponderosa*, *Venericardia tridentata*, *Donax variabilis*, and *Mulina lateralis*. No pelecypods are in life position. This mixed assemblage of both marine and estuarine species indicates two source areas for the shell material. Such a depositional environment might be related to rivermouths, inlets, or relict estuarine deposits outcropping in nearshore environments.

Thin section study of the rock indicates the cement is a blocky sparry calcite (Blatt *et al*, 1972) (Figure 12). The shell material consists predominately of molluscan fragments, many of which have been recrystallized. There is little grain to grain contact within the quartz fraction (Figure 13). Quartz grains appear to float within a matrix

Figure 12. Photomicrograph (crossed nicols) of coquina showing dark, planar, oriented shell fragments. Quartz grains are gray, calcite cement is white.

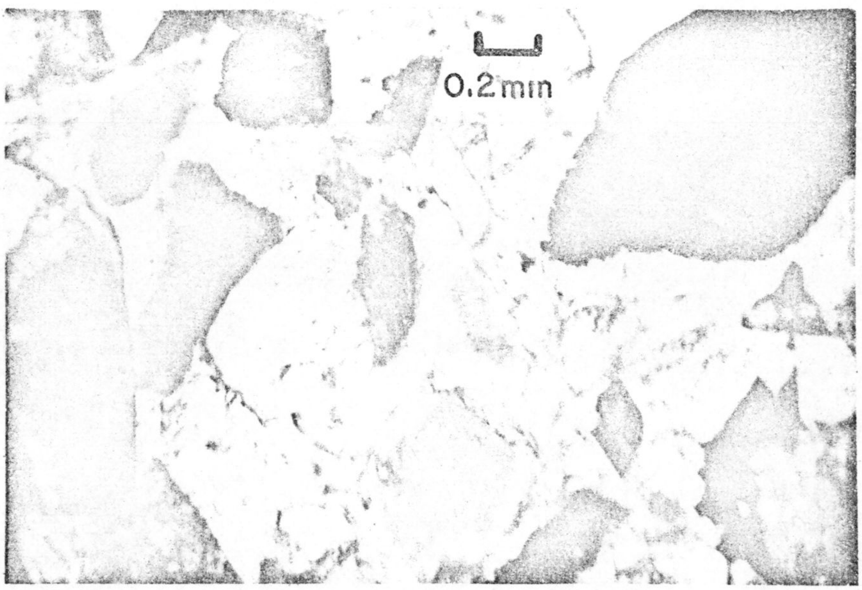

Figure 13. Photomicrograph (crossed nicols) of coquina showing quartz grains (dark gray) floating in a calcite (white) matrix.

Figure 14. Trough cross-stratification in a recently exposed coquina outcrop.

of sparry calcite. These floating grains suggest that the calcite matrix was primarily deposited as clastic calcite grains along with the quartz fraction. Diagenesis has since destroyed the clastic appearance of the carbonate grains. Feldspar, chert, limonite, and various heavy minerals occur as trace constiuents in the thin sections.

The sediment structures which dominate the rock outcrops are well developed festoon or trough cross-stratification (Figure 14). Individual curved and planar laminae range in thickness from 6 to 50 mm and average from 13 to 25 mm. Cross-bedding sets range in thickness from 15 to 60 cm. Lower bedding surfaces are concave upward to planar appearing depending upon the orientation of the outcrop surface. Strike measurements of cross-bedding laminae range from

GROUP	STRIKE RANGE	STRIKE AV.	DIP RANGE	DIP AV.	AV. CURRENT DIRECTION	FREQ.
I	N 15° to 42° W	N 25° W	10° to 24° S	19° S	N 65° E	14%
II	N 15° to 85° E	N 67° E	15° to 34° S	22° S	N 23° W	50%
III	N 50° to 87° W	N 68° W	8° to 28° S	19° S	N 22° E	36%

Table 4. Compilation of data from 43 cross-stratification measurements of the onshore coquina exposures at Fort Fisher.

N 85° E to N 87° W. Dips of cross-bedding laminae range from 8° to 35° in a southerly direction. Trough axes, where measurable, are oriented N 45° E to N 40° W and may be up to 9.1 m in length. Data from 43 cross-stratification measurements indicate that the crossbeds may be grouped in three predominant directions (Table 4). These measurements indicate predominant depositional current flow directions from the northwest and northeast. Average dips are 19° to 22° south. Previous workers, Dubar and Johnson (1964) and Fallaw and Wheeler (1969), have measured cross-stratification at the Fort Fisher outcrops. Their measurements are similar to those obtained in this study except Fallaw and Wheeler report 30% northerly dipping laminae. Only one northerly dipping unit was measured in this study. The discrepancy may be related to the removal of portions of the outcrop by wave impact and abrasion since 1969.

Harms _et al_, (1975) demonstrate the origin of trough cross-stratification by migrating dunes (Figure 15). Dunes,

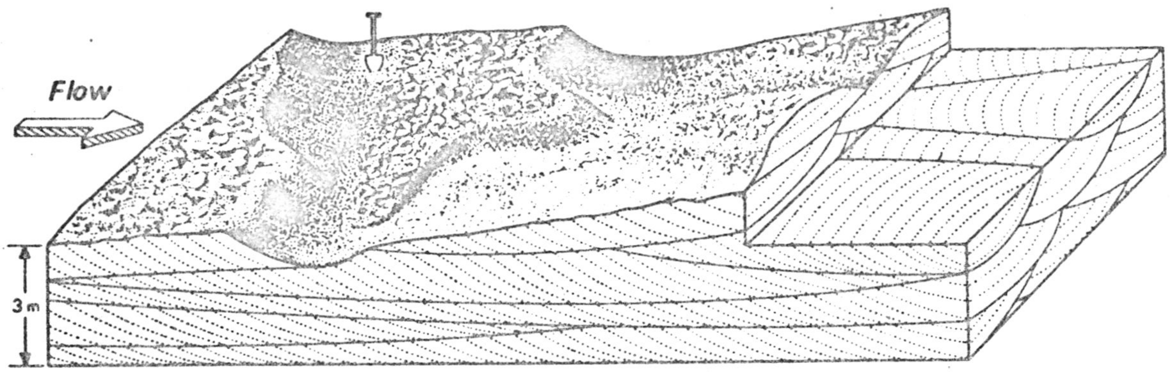

Figure 15. Formation of trough cross-stratification by migrating dunes (from Harms et al., 1975).

also termed megaripples, are formed by currents in the upper part of the lower flow regime (Harms and Fahnestock, 1965). The coquina exposed at Fort Fisher appears to have been deposited by equally predominant northeast and northwest currents characterized by the upper part of the lower flow regime.

Submerged coquina crops out on the nearshore bottom along a continuous line with the onshore outcrops (Figure 8). High energy conditions in the nearshore makes thorough investigation of the rocks difficult. Two exposures were mapped south of the onshore outcrops during the offshore survey. Additional outcrops, which are located between Traverse 7 and the coquina rock point, were mapped by the U. S. Army Corps of Engineers (1931). Another outcrop, Sheephead Rock, a well known fishing spot, consists of coquina and lies submerged 2.4 km south of the above exposures (Figure 2).

The two submerged coquina exposures mapped during the offshore survey are located on Traverses 7 and 8 and can be recognized by the distinct signature on the bathymetric profiles (Figure 16). The exposures lie in approximately 4.6 m (15 ft) of water with the upper outcrop surface forming a platform approximately 3 m (10 ft) below the water surface. Divers indicate that a ledge, approximately 1.2 m in height, forms the landward and seaward boundary of the exposure. Width of the exposed outcrops is estimated to be 10 m. The length of the submerged coquina outcrops is unknown. Evidence

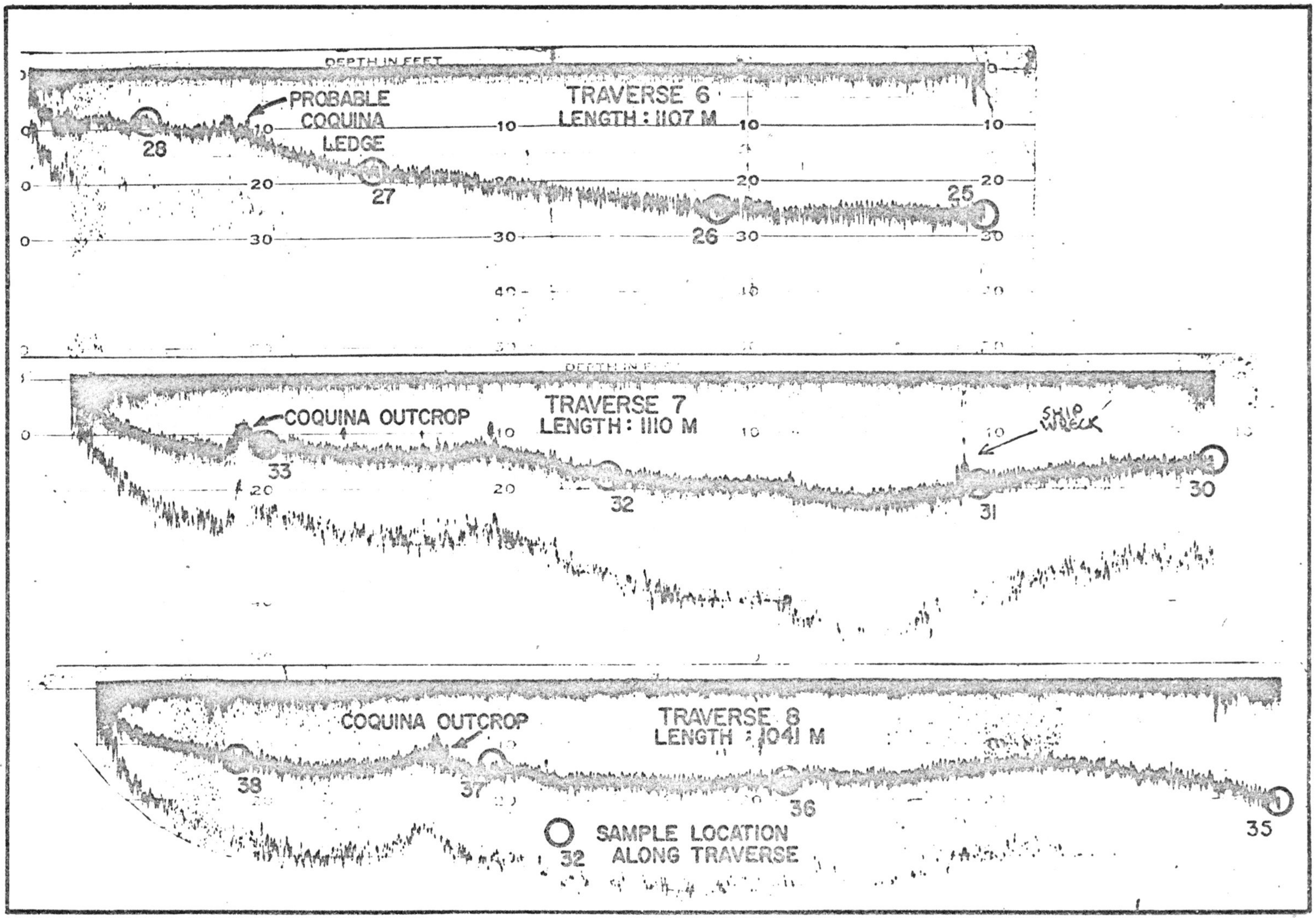

Figure 16. Bathymetric profiles and sample locations from Offshore Profile Traverses 6, 7, and 8.

for a third submerged outcrop can be seen in Traverse 6 (Figure 16). The sharp break in slope probably represents a seaward facing coquina ledge. The location of this ledge with respect to the other known coquina outcrops also suggests that coquina should outcrop here. Areas adjacent to the submerged outcrops are littered with boulder to pebble size coquina fragments. Most of the rock fragments appear abraded in a similar fashion to the debris onshore. This might suggest that the submerged outcrops were previously subaerially exposed within the forebeach.

The coquina deposits which crop out in the strandplain forebeach are habitats for numerous varieties of flora and fauna. The extent of the algae dominated flora is dependent upon the rock elevation and energy conditions. The upper surfaces of the coquina, which are wave washed but not sand covered, are dominated by lichen-like growth which is brown in color and has a leathery, spongy texture. Enteromorpha grows seaward of the dark lichen area (Figure 17). This bright green hairy algae grows only during the warmer months. Various red and brown algae grow in tide pools formed by the irregular surface of the coquina. Small barnacles (Balanus) grow within crevices and other areas which are protected from abrasion by moving sand. Mytilus, a small black to violet bivalve, lives in colonies within the rock crevices. Mytilus attaches to the rock substrate with a tough, fibrous byssus which may contribute to the corrosional processes of

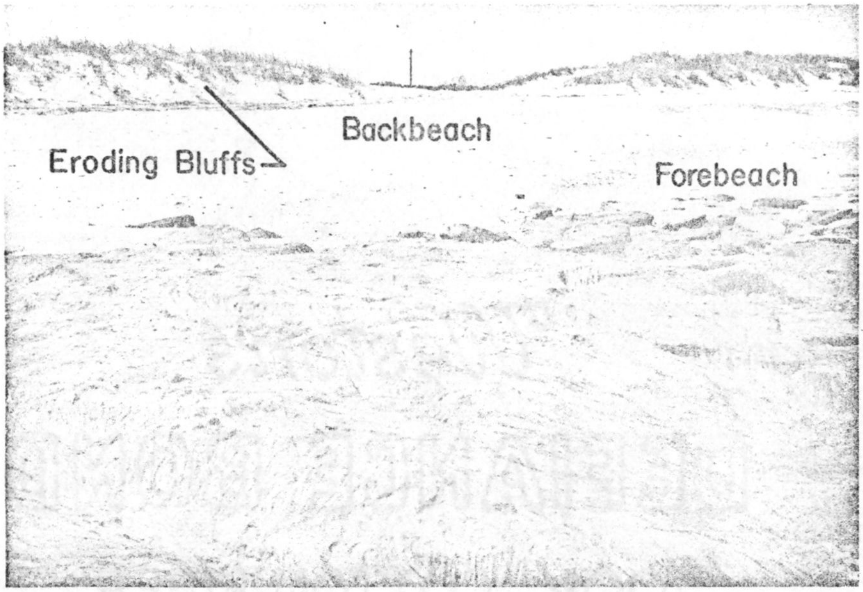

Figure 17. View, from the second coquina outcrop directed northwest, of Enteromorpha growth. Forebeach, backbeach, and eroding dune-bluff in background.

the rock. Also, Mytilus colonies trap fine sand which forms a mixed Mytilus-fine sand mat over the coquina surface. The surfaces abraded by active sediment scour and periodically buried by sand are generally free of attached algae.

The submerged coquina rock is presently being attacked biologically by destructive activities of various organisms including the rock-boring bivalve Lithophaga (Figure 18). These borings weaken the rock, thus increasing the effectiveness of the physical processes. Constructive biological processes are also occurring on the rock. Serpulid worms secrete calcium carbonate tubes on the rock surface (Figure 18). Encrusting bryozoans, the sessile bivalve Anomia aculeata, and the thumbnail-sized coral Astrangia are also constructive inhabitants of the outcrops (Figure 18). The destructive

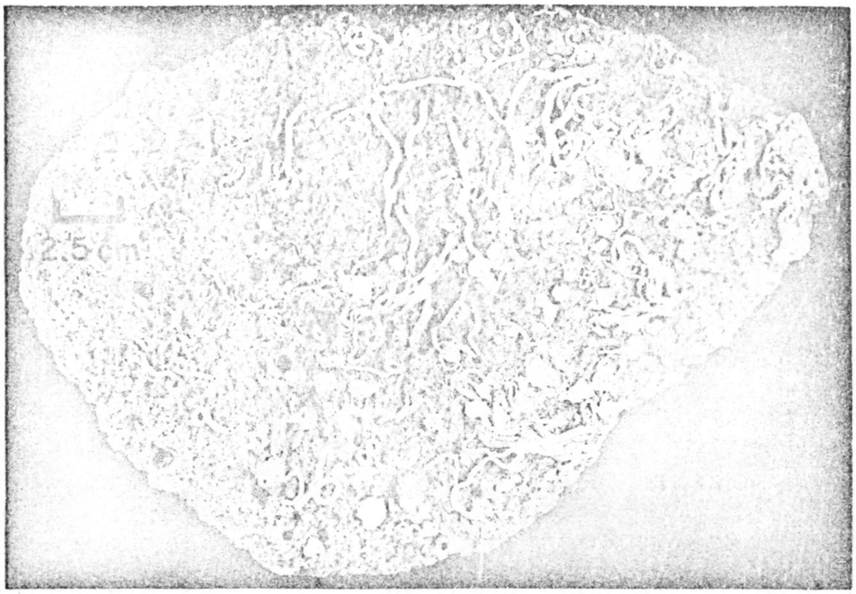

Figure 18. Sample 33 taken from a submerged coquina exposure. Note Lithophaga borings (5 to 10 mm in diameter) located on the left side of the sample.

biological processes appear to be occurring at a faster rate than the constructive processes. The submerged rocks also provide a habitat for sea urchins, sea anemones, starfish, and numerous rock-dwelling fish.

Erosional Bluff Sands

Granular, coarse to medium quartz sands are exposed in the erosional bluffs which form the landward boundary of the strandplain beach. These sands are best exposed in the bluffs north of the coquina rock point. Exposures within the cove, south of the point, consist of numerous man-made fill units and are not included in the generalized stratigraphic section. Three relict strata are recognizable above the coquina in the strandplain beach (Figure 11).

Unit I Bluff Sands. Unit I Bluff Sands conformably overly the Coquina Unit (Figure 11). The contact between the two units is rarely exposed. However, two shallow cores indicate that the contact consists of iron stained, very friable coquina overlain by approximately 5 cm of moderate reddish orange (10 R 6/6), granular, medium quartz sands. Mold structures within the coquina indicate some shell material has been removed by solution. The reddish orange sands are similar in appearance and grain size to the insoluble fraction of the coquina. Carbonate material has probably been leached from these sands also. The contact occurs approximately at the present groundwater surface. The iron staining of the coquina and sands is probably related to oxidation associated with a fluctuating groundwater table. Evidence for a conformable contact includes the lack of eroded coquina fragments in the overlying sediments and the upward gradational decrease in shell fragments.

Unit I Bluff Sands consist of 2 to 2.4 m of unfossiliferous, upward-coarsening, fine to granular coarse quartz sand with pebble and granule laminae. Gravel laminae are generally planar and 6 to 13 mm thick. Gravel is also disseminated through the unit. Composition ranges from 100% quartz sand at the base to quartz sand with 3% to 5% humate content by weight at the upper contact. The color of Unit I is quite variable and ranges from white (N 9) to dark yellowish orange (10 YR 6/6) to brownish black (5 YR 2/1) depending upon iron and humate content. The outcrop surface is mottled to massive in appearance. The upper 0.3 to 0.6 m of the unit is semiconsolidated with humate as the cementing agent. Humate content within the unit is laterally variable, with brownish black sands often grading laterally into dark yellowish orange iron stained sands within a distance of 3 m. Unit I Bluff Sands are similar in grain size, composition, and elevation to the Kure Beach Sandstone mapped by Wells (1944) at Kure Beach. Wells attributed the humate development to a swamp forest cover. These humate-rich sands are exposed in numerous localities in the Carolina Beach and Kure Beach areas.

Unit II Bluff Sands. The unconformable contact between the Unit I and Unit II Bluff Sands is very distinct due to the color difference between the generally brownish black Unit I and the moderate yellowish brown (10 YR 5/4) Unit II (Figure 19). The slightly undulatory contact contains small, filled burrows. Rounded pebble size clasts of Unit I sands are found above the contact. The unconsolidated Unit II Bluff Sands are generally 45 to 60 cm thick and consist of moderate yellowish brown (10 YR 5/5), poorly sorted, granular, coarse to medium quartz sand with 1% to 3% bleached shell hash. Quartz grains are subrounded and partially iron stained. The outcrop surface is mottled yet a few laminae are discernible. The 1.6 to 3.2 mm thick planar laminae are defined by heavy mineral concentrations, shell hash, and very coarse

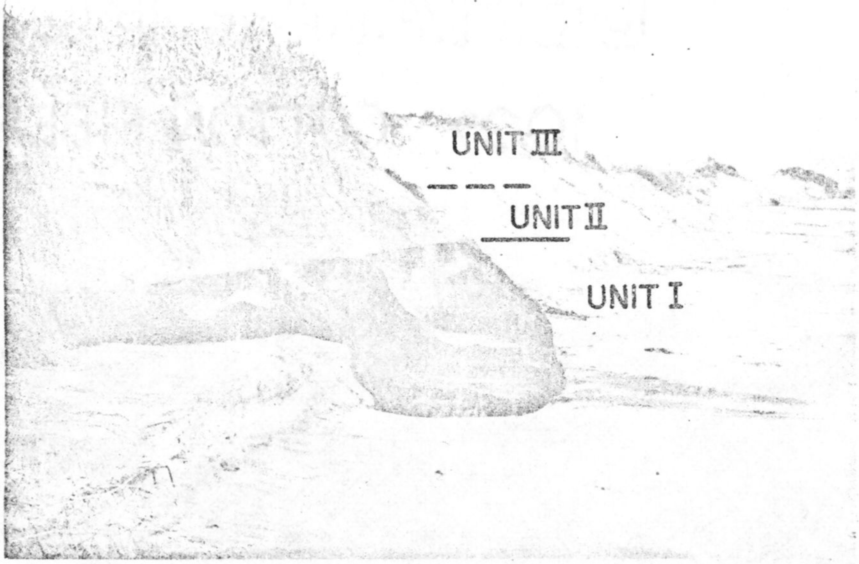

Figure 19. Contact between Erosional Bluff Unit I and Unit II Sands exposed by storm tide erosion of the strandplain beach. The Unit II and III contact is covered by slump from the dune sands above.

sands and granules. The shell hash consists of granule-sized, rounded and abraded fragments which have been subsequently bleached and partially dissolved. The upper 25 to 75 mm of Unit II consists of dark yellowish orange (10 YR 6/6), semi-consolidated muddy fine sand. This muddy layer has been burrowed in some of the exposures. The burrows are approximately 13 mm deep by 6 mm in diameter. Load casts of muddy sand protrude upward into the Unit III Bluff Sands.

Unit III Bluff Sands. Unit III Bluff Sands consist of 30 to 45 cm of laminated, moderately well sorted, granular medium to coarse quartz sands. Unit III sands are distinguished from Unit II sands by their low-angle, planar, heavy mineral laminations and pale yellowish brown (10 YR 6/2) color. Laminations dip from 1° to 10° and are defined by heavy mineral concentrations and coarse sands. The laminations become mottled upward through the unit as a result of bioturbation from the roots of sea oats (Uniola paniculata).

The unconformable contact between the Unit III Bluff Sands and the overlying modern dune sands is distinguished by an undulatory laminae of iron stained sands with a concentration of heavy minerals. Modern dune sands are devoid of bleached shell fragments and contain very little modern shell material. The quartz sands of the dune are finer grained and appear better sorted than the underlying Unit III sands.

Compacted Muddy Sandy Pebbly Gravel

A single sample (No. 25) of poorly sorted, muddy sandy pebbly gravel was collected in approximately 8 m (26 ft) of water (Figure 8). The sample had a grayish blue (5 PB 5/2) mud matrix with a gravel fraction of shell and subrounded quartz pebbles. The shell fraction, 36% by weight, consisted of the marine molluscs Crepidula and Codakia, and the estuarine forms Crassostrea, Polymesoda, and extensively bored Mercenaria. Similar Holocene deposits, which have been found extensively on the Atlantic Continental Shelf, are considered to be estuarine-lagoonal in origin (Field and Duane, 1976).

Granular Coarse Sand Unit

Sample 21, a granular coarse quartz sand, was collected at a water depth of 8.5 m (28 ft) (Figure 8). The rounded and well sorted quartz grains are slightly iron stained. This sand is included as a relict unit because of its staining and the fact that it is considerably coarser than the sediments being deposited in that area. Similar gravels and sands have been reported by Riggs and O'Connor (1974) in channeled, relict estuarine sediments of northeastern North Carolina.

MODERN UNITS

Modern Sand Units

Two gravelly sand units, which consist primarily of quartz sands and gravels containing a mixture of modern and relict shell material, are recognized (Figure 8). Unit I Modern Sands consists of slightly gravelly to gravelly, fine to medium sands. Unit II Modern Sands consists of sandy gravels and gravelly coarse to very coarse sands. In the nearshore areas adjacent to the onshore coquina exposures, Unit I and Unit II sands form a thin mantle over a coquina bottom surface. Boulders and cobbles of coquina are found mixed with Unit I and II sands throughout the offshore study area.

Both sand units are generally pale yellowish brown (10 YR 6/2). Unit I and Unit II sands are differentiated by gravel content and mean grain size (Figure 20). A comparison of Unit I and Unit II sample mean grain sizes and sorting values using the "t-test" (Folk, 1968) indicates that there is a significant difference between the two units, Unit II being coarser and more poorly sorted than Unit I. Both Unit I and II contain modern and relict whole shells in about equal proportions. Modern whole shells are mostly marine and consist of Arca, Olivella, Tagelus, and Solon. Relict whole shells consist of both marine and brackish water fauna, such as Crepidula, Crassostrea virginicus, and Mercenaria mercenaria. Relict whole shells are black stained and may be extensively bored. The shell fraction also contains fragments of various gastropods, sand dollars, and echinoid spines.

Observations made by the divers during the offshore survey indicated that both sand units were generally covered by straight ripplemarks with 10 to 13 cm trough depths and 15 to 20 cm wavelengths. However, poor visibility and strong currents during the survey severely limited the examination of the bedforms occurring on the surface of Units I and II.

Unit I Modern Sands. Unit I Modern Sands consist of fine to medium quartz sand mixed with gravel and shell material. The gravel content ranges from 1% to 18% and consists of granule and pebble-sized shell fragments, quartz, and coquina fragments. The mud content of Unit I ranges from 0 to 8%.

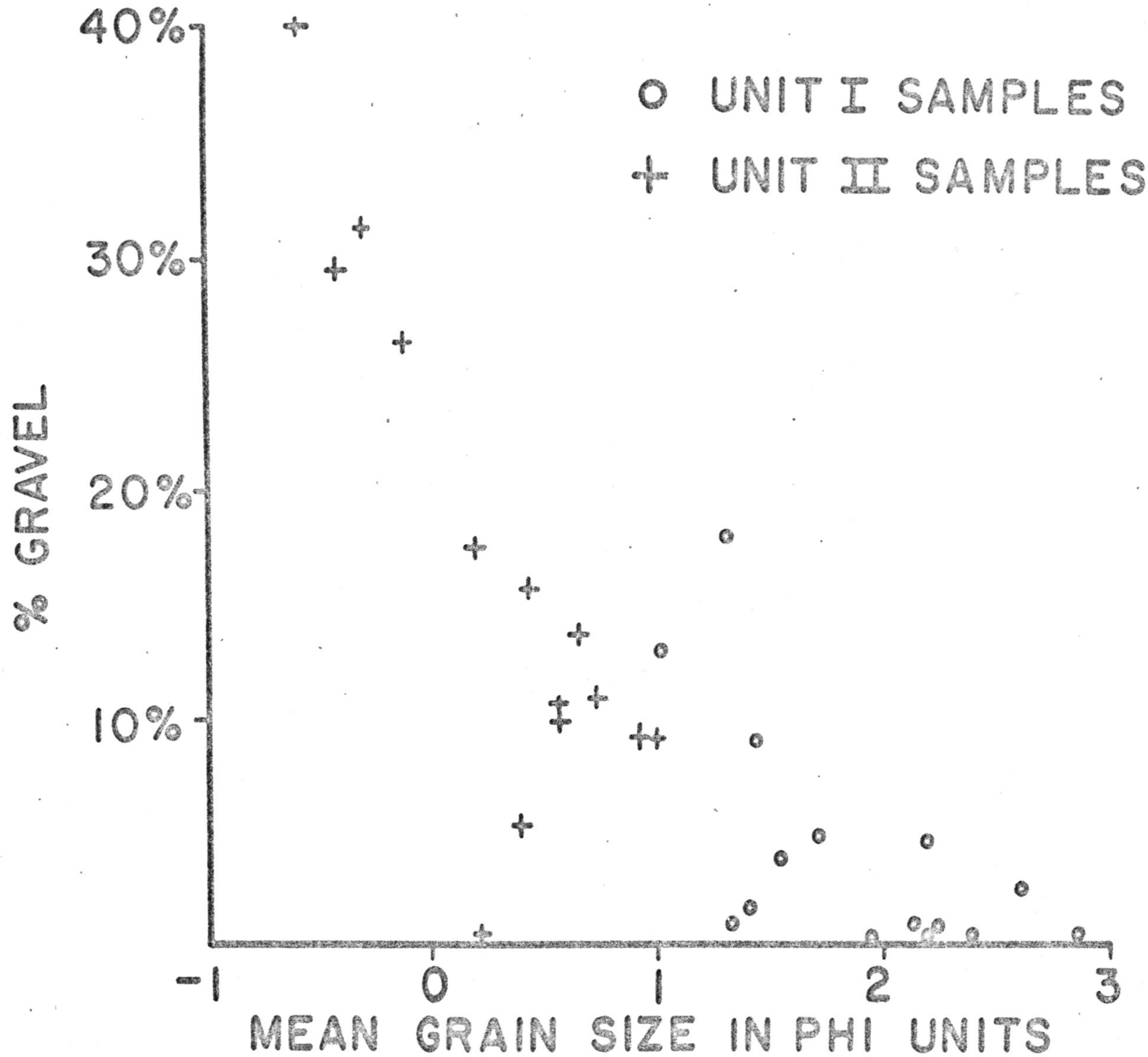

Figure 20. Plot of gravel percentage versus mean grain size of the Unit I and Unit II Modern Sand samples.

Unit I is moderately shelly with shell contents varying from 0.1% to 22%. The Unit I nonshell sand and granule fraction is 98% to 100% quartz. This quartz fraction may be clear or pale yellow in color as a result of slight iron staining. Sources of these iron stained quartz grains could include the relict erosional bluff sands, disaggregated coquina, and the two offshore relict units. The quartz grains are subangular to subrounded with granules and iron stained grains being generally more rounded than clear quartz grains. Unit I sediments contain up to 2% heavy minerals and phosphate grains.

Unit II Modern Sands. Unit II is similar to Unit I except it is more poorly sorted and has a coarser mean due to a greater gravel content. Unit II Modern Sands consist of sandy gravels and gravelly coarse to very coarse quartz sands. The gravel content ranges from 5.2% to 40.7% and is comprised of granule and pebble-sized shell fragments, quartz, and coquina fragments. Coquina fragment composition varies from 0 to 19.6%. Mud content ranges from 0 to 0.16%. Unit II sorting ranges from moderately sorted to poorly sorted. Clear and iron stained quartz comprises 99% to 100% of the nonshell fraction with very minor amounts of heavy minerals and phosphate occurring. Unit II sands are more rounded than Unit I sands, ranging from subrounded to rounded.

Organic-rich Mud

The Organic-rich Mud Unit occurs in water depths of 7 m (23 ft) to 9.1 m (30 ft) (Figure 8). The mud seems to occur as an ephemeral blanket-like deposit which overlies Unit I and Unit II Modern Sands and/or the various relict units. Divers reported the mud to be 15 to 45 cm thick overlying a hard sand bottom; however, no sample was taken of the sediment surface below the mud. At some sample locations, the divers reported the organic-rich mud surface to be ripplemarked. The mud is olive black (5 Y 2/1) when wet, dries to a medium dark grey (N 4), and gives off a very offensive stench. The water content, when sampled, is estimated to be about 90% by weight. The mud is comprised of sand and granule-sized fecal pellets with minor amounts of very fine sand and silt. Small, delicate, whole and fragmented marine bivalves also occur within the organic-rich mud. A very approximate organic content of the unit, based on two samples, ranges from 10% to 13%. X-ray diffraction analysis of one sample's inorganic clay content indicated a composition of dominately smectite with minor amounts of illite and kaolinite (Duque, personal communication).

Two possible sources exist for the mud presently accumulating in the offshore area. It could represent the suspended load being discharged by the estuaries and the Cape Fear River, or it could be derived by the biological and physical erosion of the outcropping Holocene estuarine deposits on the inner continental shelf.

PRESENT SHORELINE PROCESSES

Processes occurring along the strandplain beach in the study area are quite different from those of the barrier beach to the south. The strandplain processes, which are dominantly erosional in nature, are greatly affected by the presence of coquina cropping out within the forebeach. Barrier beach processes are constructional and are dominated by deposition from longshore sediment transport and overwash.

Shoreline processes are driven by a very complex and variable set of forces which include astronomical tides and wave energy resulting from storm winds and surge. An unconsolidated sand beach, such as the Fort Fisher barrier beach, forms a 3-dimensional equilibrium profile which is a direct response to a specific energy regime; the equilibrium profile changes in direct response to changing energy conditions (Riggs, 1976). If a portion of the beach is stationary and cannot respond to energy changes, a disequilibrium situation develops. The stationary coquina outcrops within the strandplain forebeach produces such a disequilibrium condition in which erosion becomes the dominant process. The nearshore sediment distribution also responds in a similar manner and is greatly influenced by nearshore topography and structural controls.

STRANDPLAIN BEACH PROCESSES

Progressive shoreline development related to the sequential exposure of coquina outcrops occurs within the strandplain beach. The initial cropping out of coquina along the northern strandplain beach represents the beginning stage of coquina-influenced shoreline development, while the submerged coquina exposures in the southern portion of the nearshore study area represent the final stage. This progression of shoreline development can be observed along the present shoreline and nearshore area.

The Fort Fisher strandplain shoreline trends N 15° E. The coquina exposures in and north of the study area are aligned along a N 3° E strike (Figure 8). Because of the orientation of the strandplain with respect to the coquina, the rock becomes exposed further northward as the shoreline recedes. Thus, the oldest rock exposures occur in the south whereas the newest exposures are presently being uncovered on the north end of the study area. This progressive northward exposure of the coquina can be seen following high energy storm periods (Figure 21).

The shoreline north of the present coquina exposures has receded at an average rate of 0.79 m/yr during the period 1931 to 1967 (U. S. Army Corps of Engineers, 1974). This shoreline recession occurs primarily in response to high energy storm regimes. As the shoreline recedes, new outcrops

Figure 21. Recent exposure of coquina from storm erosion of the strandplain forebeach. Second coquina outcrop in upper right of the figure.

Figure 22. View, directed southeast, of the second coquina outcrop. At this stage of shoreline development, the outcrop forms a shelf-like projection into the forebeach.

of coquina are exposed in the forebeach producing a steep immobile forebeach profile. This results in a higher energy per unit area which does not readily allow sand to be redeposited over the rock. If shoreline recession has not been too extreme, forebeach sand deposition will probably rebury the new exposure as the energy subsides. This process of exposure and subsequent burial may occur repeatedly over a period of months or years.

With continued shoreline recession, the rock forms a platform-like projection which continues to extend further into the forebeach area (Figure 22). Normal wave swash over the rock surface during the regular high tides eventually removes the backbeach-berm sand leaving the adjacent bluff totally unprotected against wave attack during the higher storm tides (Figure 23). Some of the sediment eroded from the bluff may be deposited as a thin, ephemeral, ripplemarked veneer over the rock surface (Figure 24) or it may be swept off the northern or southern ends of the outcrop depending upon wave direction and size. The forebeach sand and coquina interface is often scoured by fast flowing currents which move laterally over the rock surface.

At this stage of coquina exposure, the rock is actively eroded by the physical processes of wave impact and sediment abrasion along the seaward portion of the rock platform. The seaward face of the outcrop is irregular and contains many depressions and crevices which become partially filled

Figure 23. Strandplain bluff eroded approximately 0.5 m by storm tides during an extratropical storm, September, 1977.

Figure 24. View, directed south from the second coquina outcrop, of ripplemarked sands deposited over the landward portion of the coquina platform.

with coarse sands, pebbles, and shells. The action of breaking waves swirls these materials around, abrading the softer coquina. This abrasion may take the form of small pot-holes (Figure 25) or large abrasion "bowls" along the ledge front (Figure 26). During the highest energy periods, plunging waves often break off whole bedding units of the rock. These tabular boulders aid in breaking off additional pieces of the outcrop and are themselves reduced in size by continued abrasion (Figure 27). The role of biologic corrosion at this stage is probably minimal.

Continued abrasion produces a distinctive seaward ledge of rock below sea level which acts as a barrier to the shoreward transport of littoral sediments. Only finer, suspended sands are transported landward over the rock ledge. Thus, the sand eroded from the backbeach and bluffs during high energy events cannot be replaced during lower energy conditions. Minor, ephemeral sand deposition does occasionally take place over the landward portions of the rock platform during high energy conditions coupled with a falling tide. These sands are rapidly removed during the next high tide.

The rock projections also act as low groins trapping sediment (if available) on the updrift side of the outcrop, while sediment is removed on the downdrift side. Both north and south flowing littoral currents occur in the study area. However, the dominance of a north to south littoral drift produces a net sediment loss south of the outcrops. This

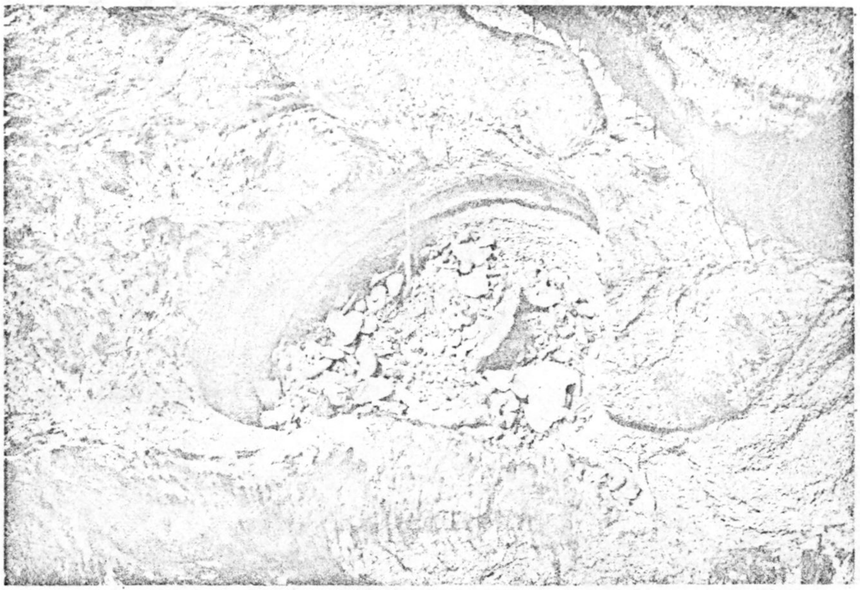

Figure 25. Pothole in the seaward portion of a coquina outcrop surface, approximately 0.4 m in diameter.

Figure 26. Abrasion "bowl" within the seaward ledge of a coquina platform.

Figure 27. Large coquina blocks, 0.5 to 1 m in length, which have been pushed landward from the coquina platform by storm waves and swash.

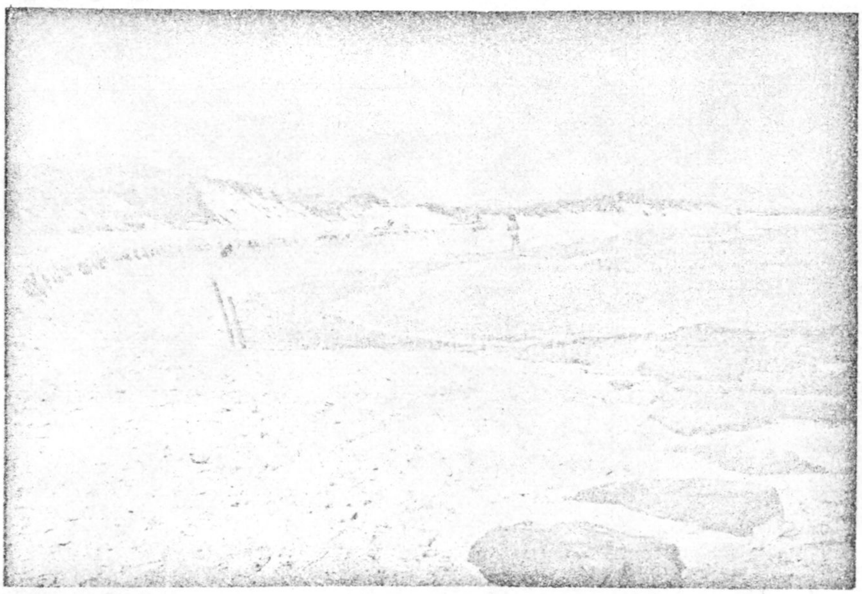

Figure 28. View, directed north from the coquina point, of large cusp developed between the 2nd outcrop (in right background) and the rock point.

sediment loss increases shoreline recession to form a regional cusp or cove south of the outcrops (Figure 28). The resulting forebeach profiles within the cove are considerably steeper due to the deficient sediment supply (Figure 29).

At this point in the shoreline's development, the cove becomes a prominent feature of the shoreline. The coquina platform has been extensively eroded in a landward direction and lowered in elevation (Figure 30). The rock may form a distinct "point" with a large cove to the south and a smaller developing cove to the north (Figure 31). The exposed portions of the south side of the rock point are gradually removed by continued wave impact and abrasion, producing a submerged rock surface. Continued sand removal increases the steepness of forebeach profiles and the rate of shoreline recession increases in the cove. The now submerged rock south of the point continues to be destroyed as a result of increased biologic corrosion in conjunction with the physical abrasion. A seaward ledge is still prominent and continues to act as a barrier to shoreward transport of littoral sediments. Eventually, the southernmost submerged exposures become breached or eroded low enough to allow the reestablishment of shoreward transport of the littoral sediments back to the beach system south of the cove (Figure 32).

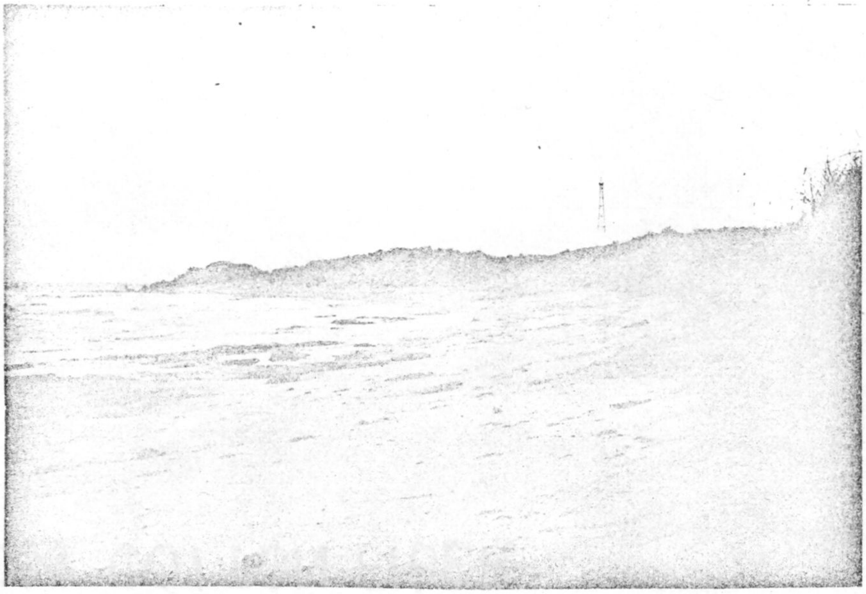

Figure 29. View, directed south from the second outcrop, of steep forebeach profiles resulting from an extratropical storm.

Figure 30. View, directed south, of the older coquina point outcrop which has been significantly eroded and lowered in elevation.

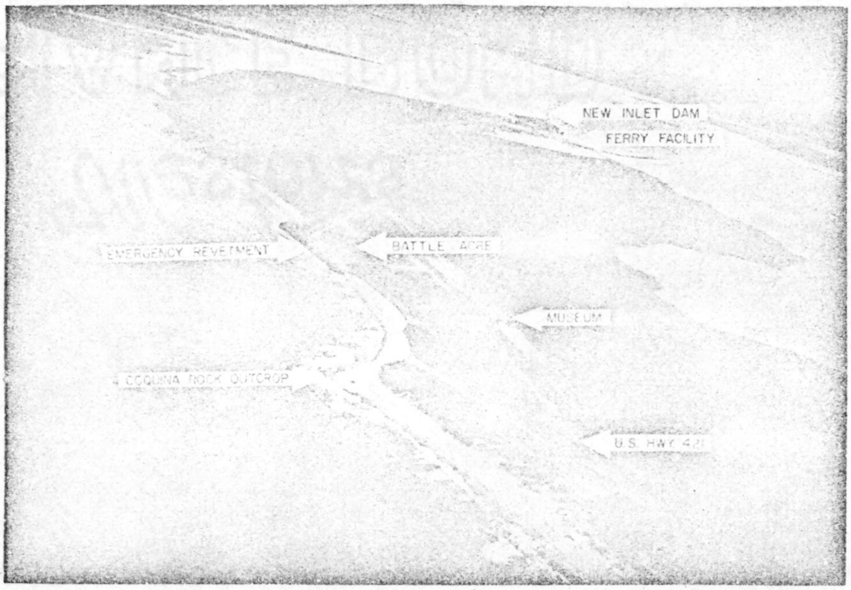

Figure 31. Oblique aerial view of the Fort Fisher shoreline. Note the large cove or shoreline indention south of the rock point (Photograph from U. S. Army Corps of Engineers, 1974).

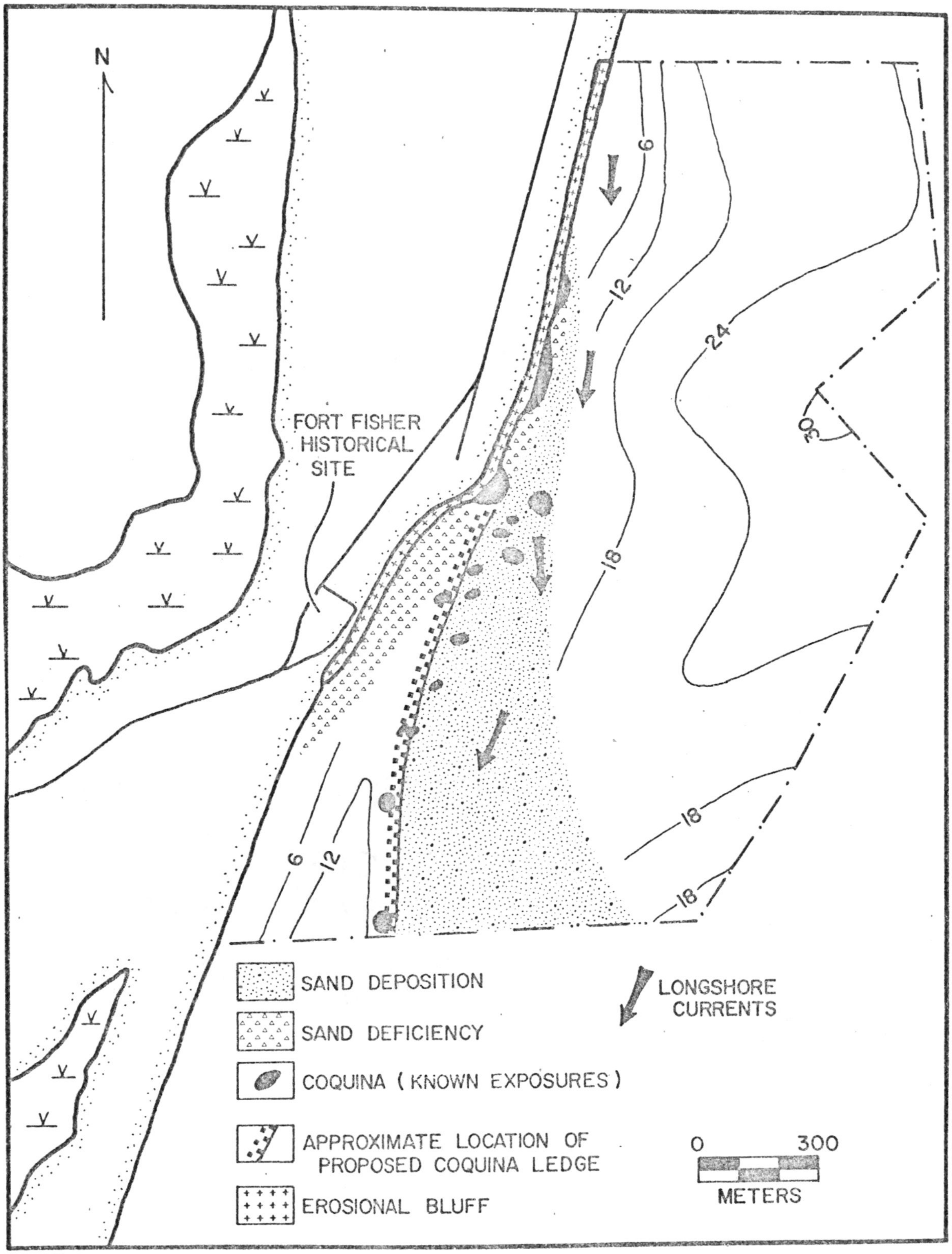

Figure 32. Diagrammatical map of inferred nearshore processes.

SEDIMENT DISTRIBUTION

The distribution of modern units is directly related to 1) source area, 2) structural controls, and 3) water depths (Figure 8). The location of the Organic-rich Mud Unit appears to be related to water depth. The majority of the mud is located in a trough-like depression bounded by the 22 ft depth contour (Figure 8). Organic-rich mud is also located in the northeastern corner of the study area in 7 to 7.3 m (23 to 24 ft) of water (Figure 8). The presence of the organic-rich mud reflects the general existence of low energy conditions below the 22 ft contour. During storm conditions, however, it is expected that the mud is probably resuspended into the water column. The location of organic-rich mud may also be related to a source area. The physical and biological erosion of the adjacent relict Compacted Muddy Sandy Pebbly Gravel Unit (mud content 8%) could provide one potential source for the mud.

The distribution of Unit I and Unit II Modern Sands is related to source area and structural controls. The coarser Unit II sands which are located adjacent to the shoreline in areas A, B, and C (Figure 8), reflect the winnowing effect of the higher energy surf zone. Areas A and B receive considerable amounts of coarse quartz sands and granules which have been eroded from the relict Erosional Bluff Sand and Coquina Units. Unit I Modern Sands are located generally seaward of Unit II Sands throughout the study area. These sands reflect decreasing energy with increasing depth seaward of the surf zone.

The sediment distribution within the southern two-thirds of the study area is dominated by two structural and topographic controls. The most important control is the location of coquina outcrops (Figure 8). The seaward facing ledges of onshore and submerged coquina outcrops act as a barrier to the landward transport of the north to south moving littoral sediments (Figure 8). The presence of the finer-grained Unit I sands in area D, south of the onshore coquina outcrops and landward of the offshore submerged exposures supports this hypothesis. Coarser Unit II Sands in area E are structurally bounded by the coquina ledge on the west and the bathymetric ridge on the east (area F). This topographic "pocket" acts as a sediment sink for north to south moving, coarse littoral sediments. The Unit I Sands in bathymetric ridge area F, probably represent a reworked ebbtide delta sand shoal associated with the New Inlet prior to 1881 as discussed in the section entitled "Shoreface Bathymetry Changes".

Mean Grain Size Map

The graphic mean grain size (Folk, 1968) of each sample was plotted and contoured (Figure 33). An anomalous area of fine sediments, located just south of the onshore coquina exposures, may result from a sorting process which allows only the finer littoral sediments to pass landward up and

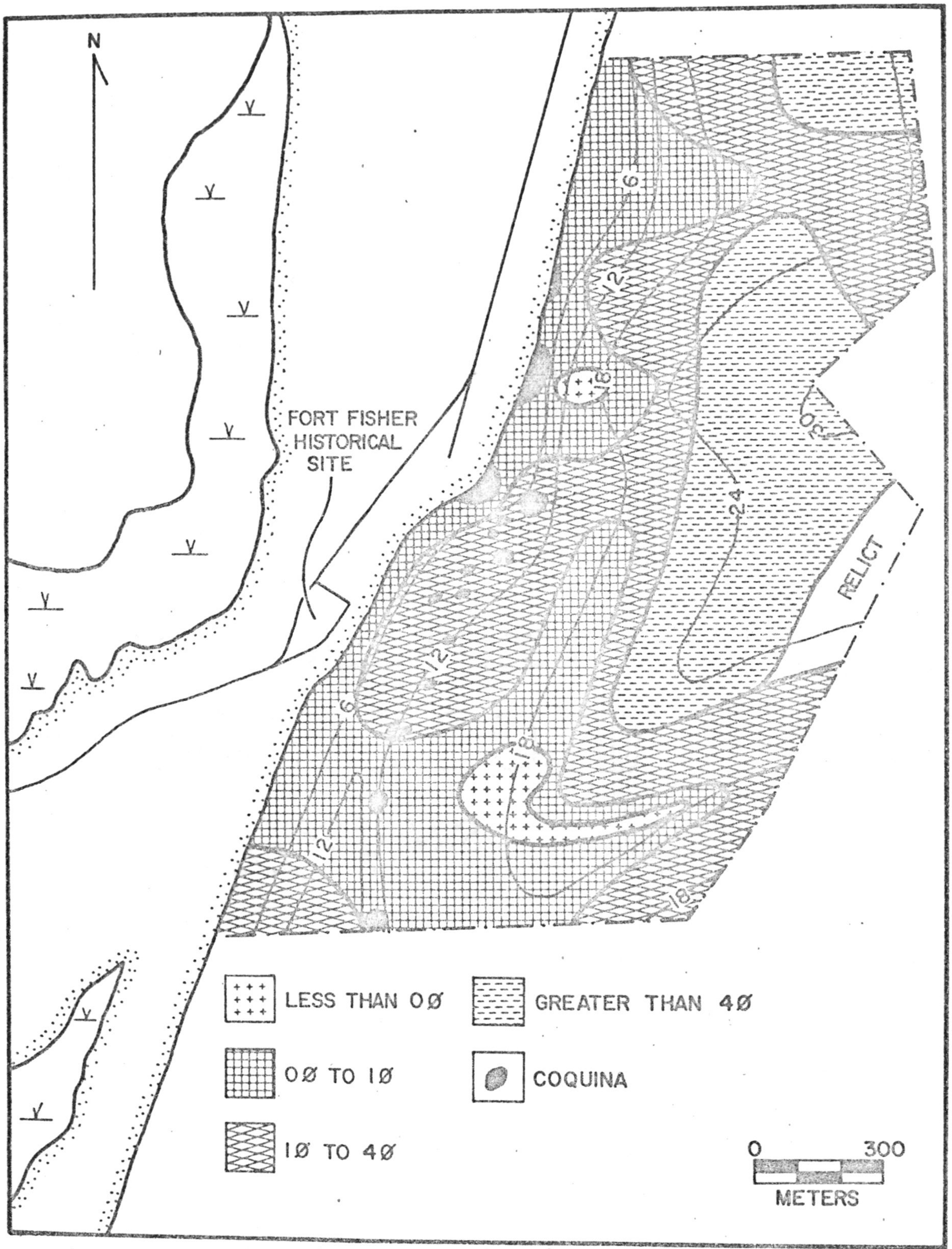

Figure 33. Graphic mean grain size map.

over the submerged coquina ledges. The occurrence of coarse sands adjacent to most of the shoreline reflects the winnowing effect of the higher energy surf zone and the eroding strandplain bluffs as a source area.

Sediment Sorting Map

Inclusive graphic standard deviation (Folk, 1968) values for the samples were plotted and contoured (Figure 34). Unit I sands are generally moderately to moderately well sorted. Unit II sands are poorly sorted. Fine-grained sands and organic-rich muds are moderately well sorted. High energy nearshore sediments are generally poorly sorted.

Shell Content Map

The weight percentage of shell material in each sample was plotted and contoured (Figure 35). Shell fragment percentage generally reflects the gravel content of the sample. Samples with the lowest shell fragment percentages occur in the highest energy nearshore environments and in the organic-rich mud areas. Highest shell fragment percentages are related to more moderate energy environments with cleaner, mud-free sands. The higher percentages probably reflect higher populations of shell fauna species or a proximal source of eroded and reworked fossil shell material. Fossil shells comprise up to 20% of each sample's shell fragment fraction.

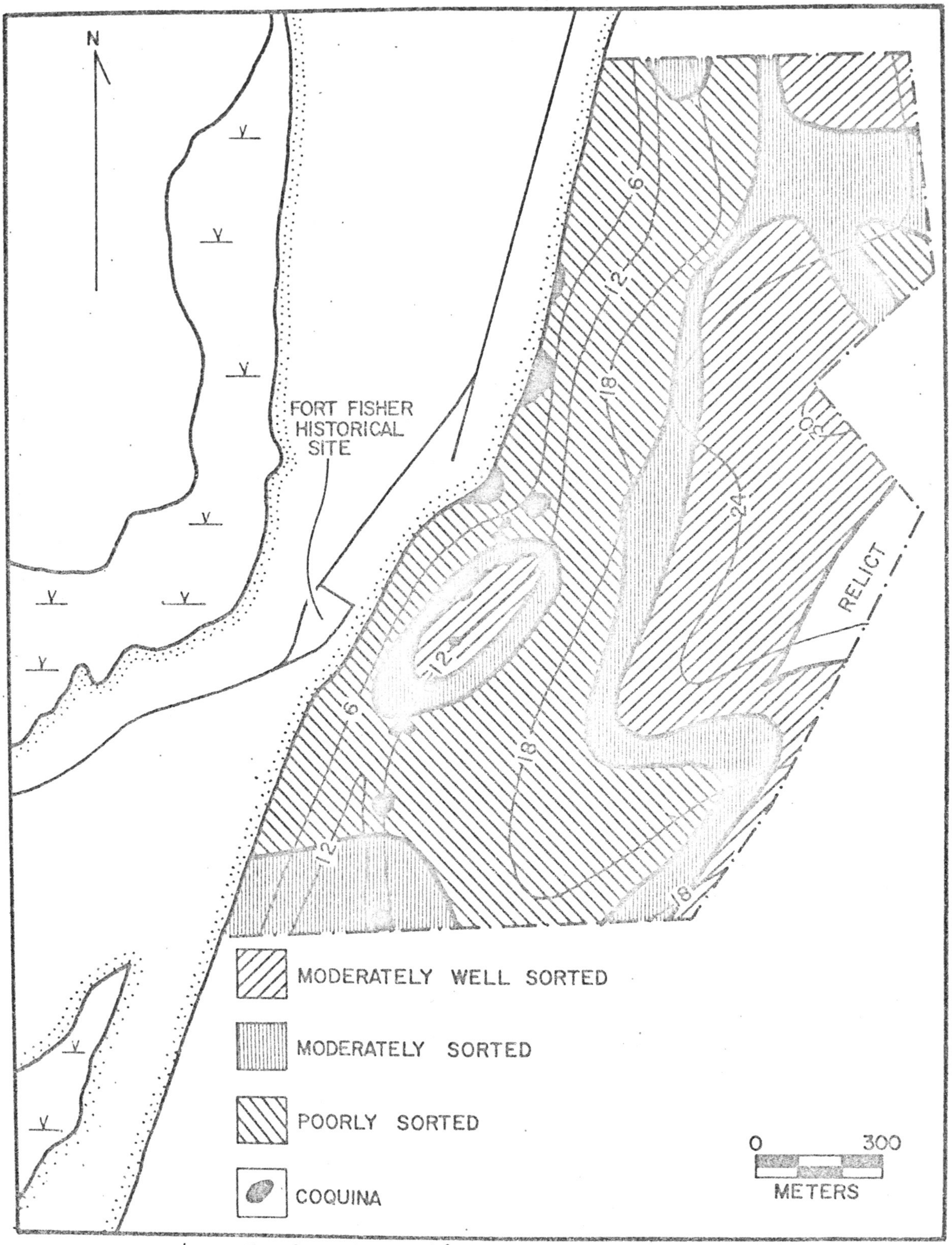

Figure 34. Sediment sorting map.

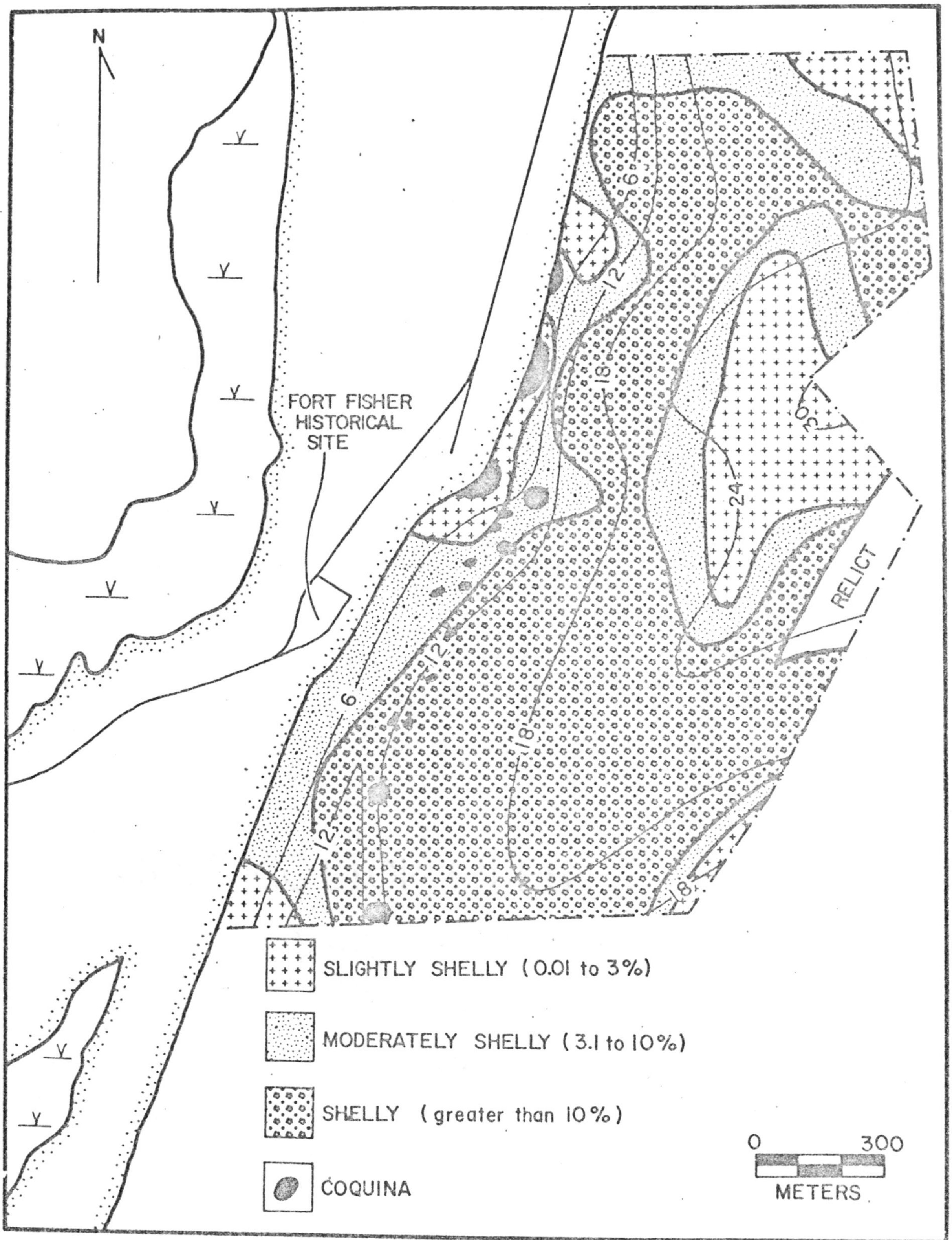

Figure 35. Map of shell content.

Coquina Fragment Content Map

Coquina fragments within Unit I and II Modern Sands are rounded and pebbly to very coarse sand size. Highest coquina fragment percentages occur directly offshore and south of the eroding, emerged outcrops (Figure 36). This distribution reflects the dominant southerly littoral transport within the study area. It is important to note that this map does not reflect the vast amount of coquina cobbles and boulders which are strewn across the nearshore bottom.

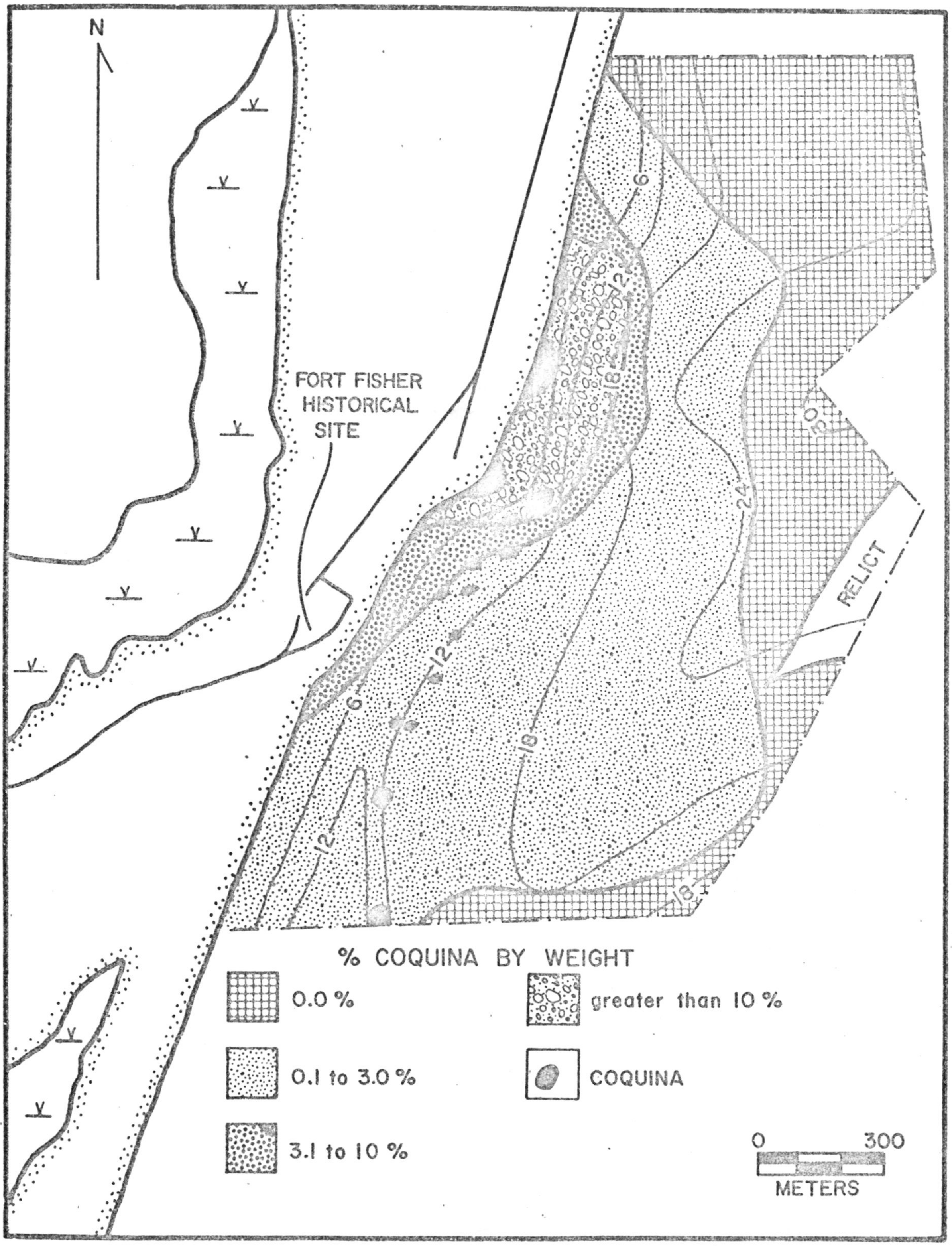

Figure 36. Map of coquina fragment content.

H I S T O R I C   S H O R E L I N E   C H A N G E S

Shoreline and bathymetry surveys in the Fort Fisher area date back to 1852. The U. S. Army Corps of Engineers has been concerned with the inordinate erosion rate at Fort Fisher and has collected detailed information since 1931. A synthesis of this data outlines the basic patterns of shoreline movement that have occurred in the Fort Fisher area since 1852.

SHORELINE MOVEMENTS

Figures 37, 38, and 39 show the locations of former shorelines in the Fort Fisher area. The sources of the shoreline location data are listed in the section entitled "Methods of Study". Many problems are encountered when working with these older shoreline and hydrographic maps. For example, many surveys were not tied into reliable triangulation points while some surveys were made using very odd scales (U. S. Army Corps of Engineers, 1931). Also, the U. S. Coast and Geodetic surveys were concerned primarily with the offshore bathymetry and not the detailed shoreline location. At best, the pre-1931 shoreline locations used in this study are tenuous. However, they should be able to supply some information for establishing patterns of relative shoreline movements.

The strandplain beach, lying directly seaward of the Fort Fisher Historic Site, has experienced both dramatic

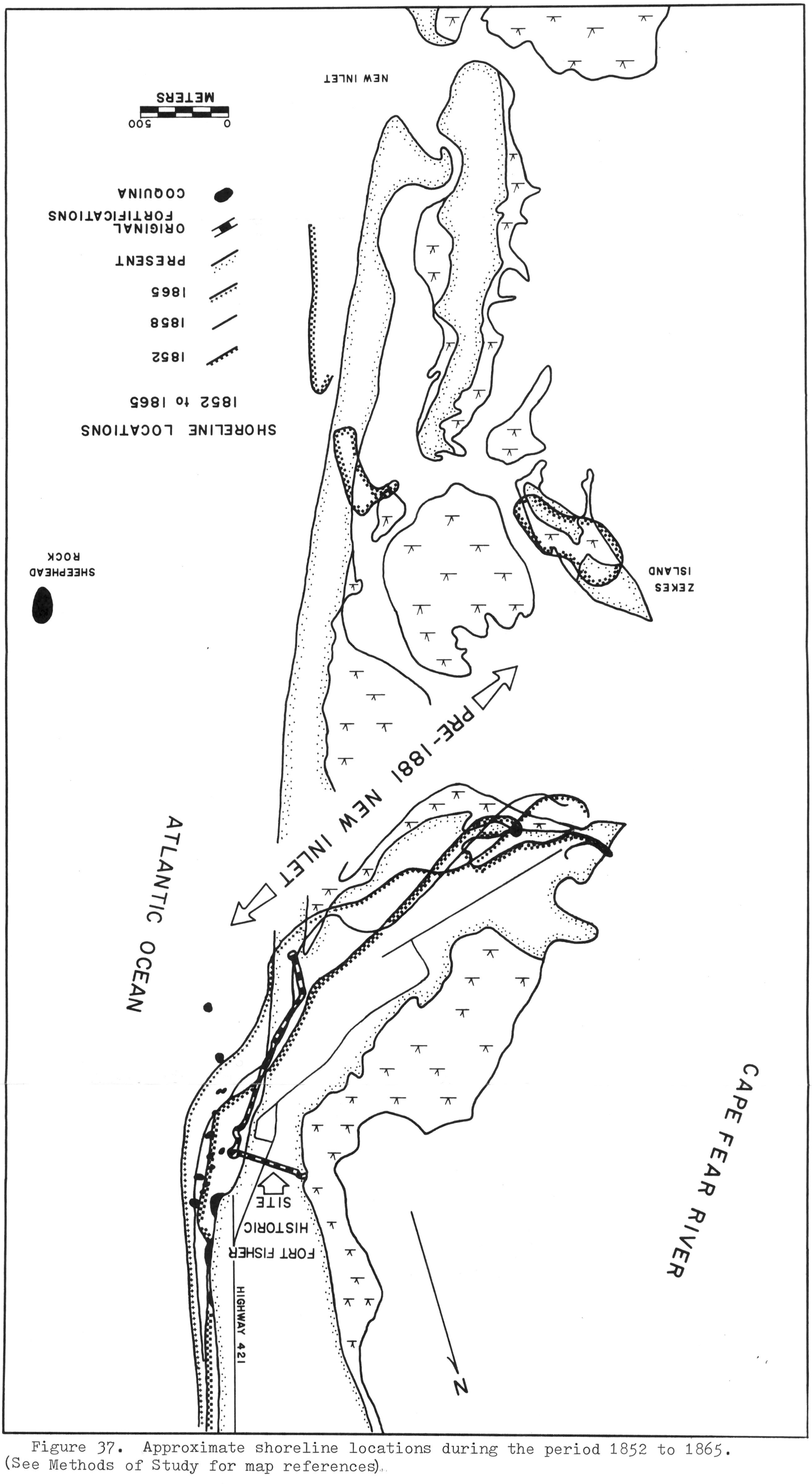

Figure 37. Approximate shoreline locations during the period 1852 to 1865. (See Methods of Study for map references).

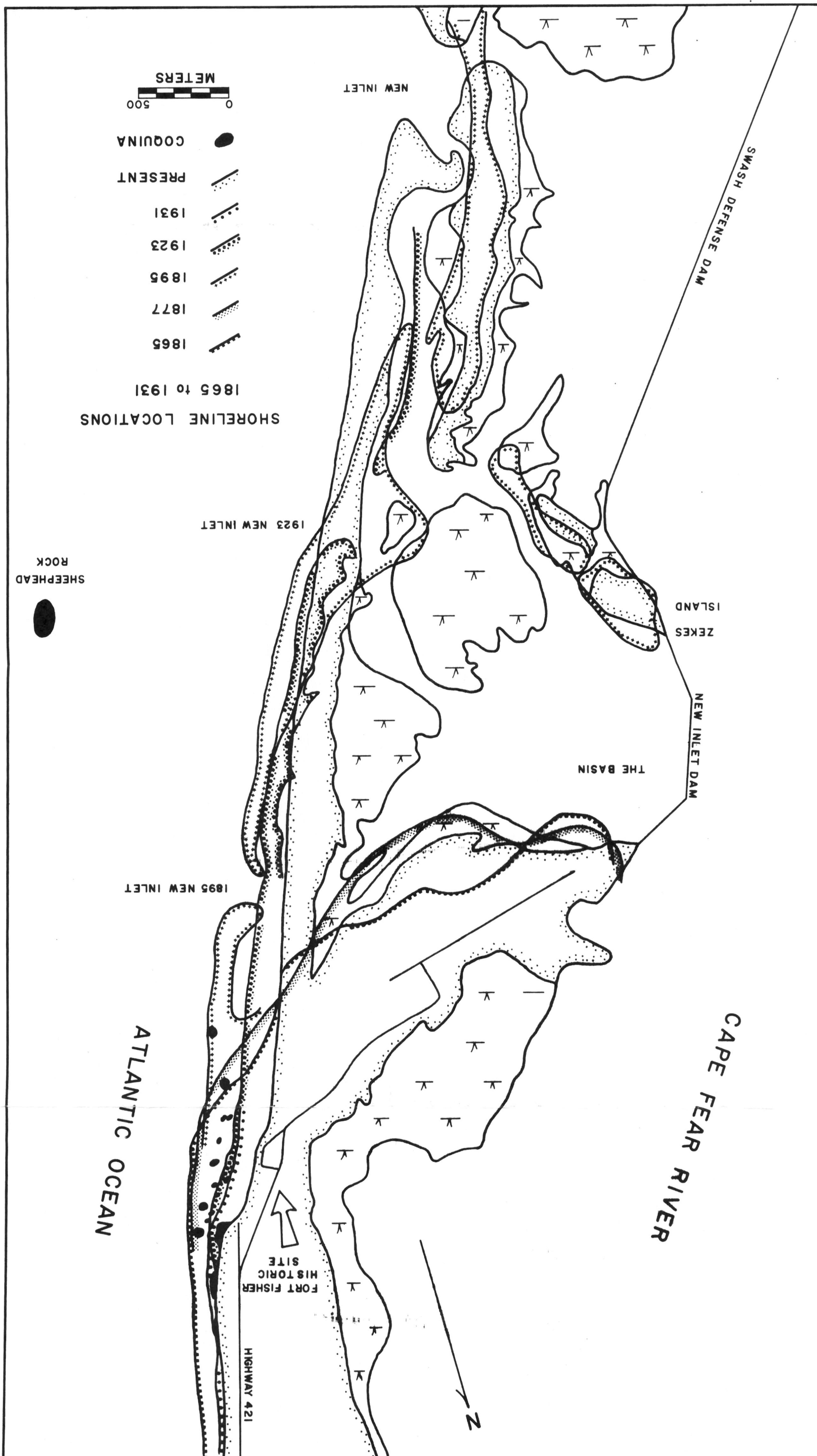

Figure 38. Approximate shoreline locations during the period 1865 to 1931 (See Methods of Study for map references).

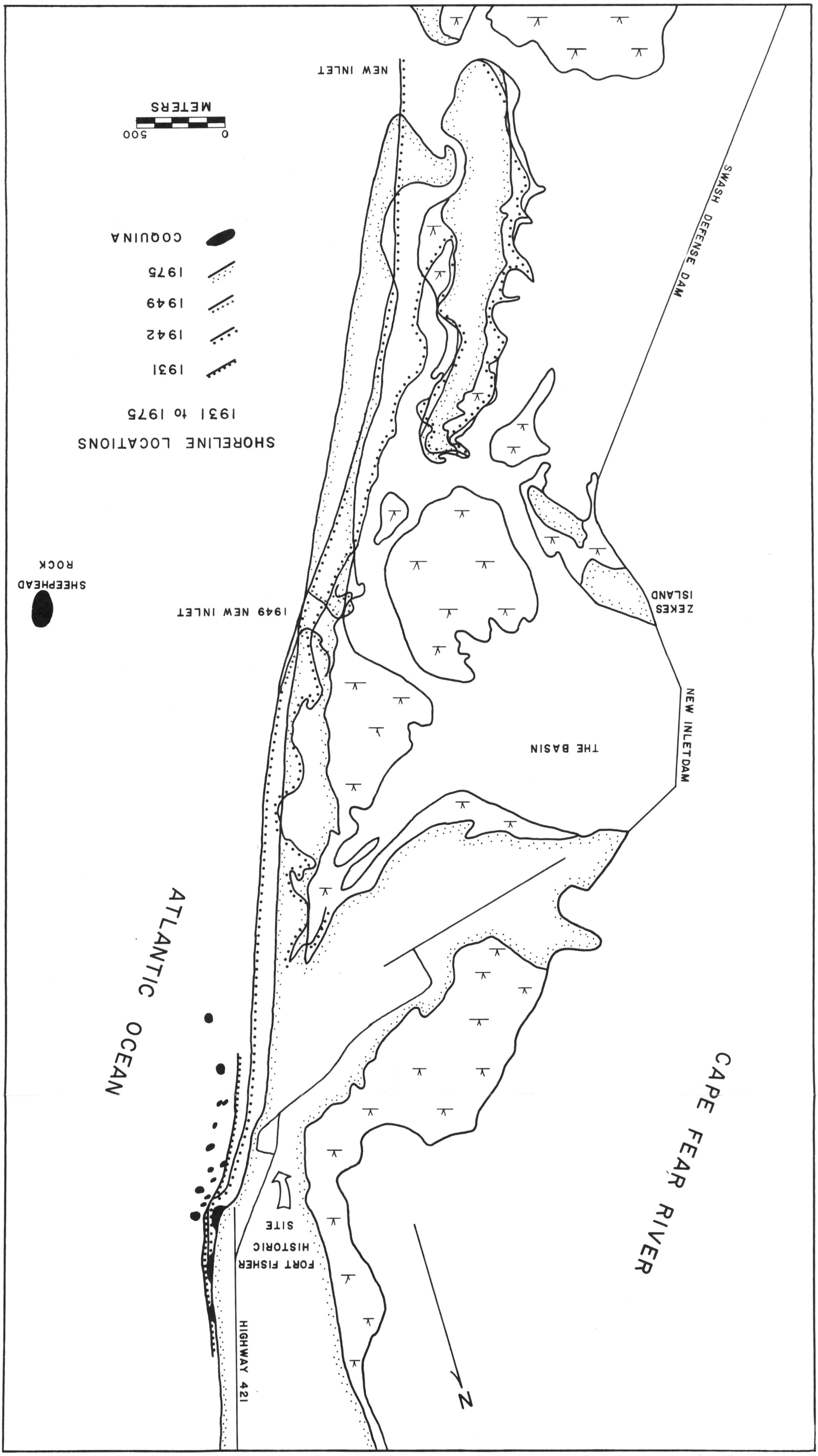

Figure 39. Approximate shoreline locations during the period 1931 to 1975 (See Methods of Study for map references).

progradation and recession. During the period 1852 to 1865, this area experienced an estimated 153 m of net shoreline accretion which occurred at an average rate of 11.8 m/yr (Figure 37). Much of this accretion may have actually occurred since 1761 when New Inlet was first opened by a "fearful hurricane. . . which did great damage" (Waddel, 1909). The accretion was probably related to the development of an ebb-tide delta associated with the 1761 New Inlet.

The shoreline had reached its apparent maximum seaward progradation by 1865 (Figures 37 and 38). Minor shoreline recession, 36 m, occurred during the period 1865 to 1878 (Figure 38). The New Inlet Dam, completed in 1881, almost completely blocked the flow of the Cape Fear River out of New Inlet. As a result, the fresh water hydraulic head was drastically reduced through the inlet. This reduced pressure allowed a narrow barrier spit to grow southward across the inlet mouth. By 1895, this spit had extended approximately 0.73 km southward. During this same period, 1878 to 1895, approximately 27.4 m of erosion occurred in front of the Historic Site (Figure 38). During the period 1895 to 1923, the entire shoreline receded 168 m at an average rate of 6.4 m/yr (Figure 38).

By 1923, the shoreline had receded to the approximate location of the 1852 shoreline. The 1923 shoreline appears to develop a more irregular configuration as the coquina becomes exposed. During the period 1923 to 1926, an estimated

18 m of net shoreline accretion occurred (U. S. Army Corps of Engineers, 1974). In 1926, an estimated 4,600 m^3 of coquina was quarried and removed from the beach northwest of the Historic Site. Approximately 85 m of erosion occurred in the 5 year period after the removal of the rock (U. S. Army Corps of Engineers, 1931). The removal of rock accelerated the erosion rate and probably promoted the establishment of a cove south of the rock point (Figure 38).

Since 1931, the shoreline in front of the Historic Site has receded approximately 145 m at a rate of 3.2 m/yr (Figure 39). The shoreline at the coquina rock point has receded northwestward approximately 76 m. The strandplain beach north of the point has eroded from 30 to 76 m during this same period. A small cove has developed south of the present rock point. The coquina outcrop itself, which forms the point, appears to have eroded approximately 100 m since 1931. The erosion removed mostly the upper surface of the rock body leaving submerged outcrops in the adjacent nearshore.

NEARSHORE BATHYMETRY CHANGES

Nearshore bathymetry in the vicinity of the Fort Fisher Historic Site is presented in two periods; Figure 40 represents the period from 1872 to 1923, while Figure 41 depicts the period from 1923 to 1976. Changes in bathymetry from 1872 to 1923 represent the nearshore system's response to

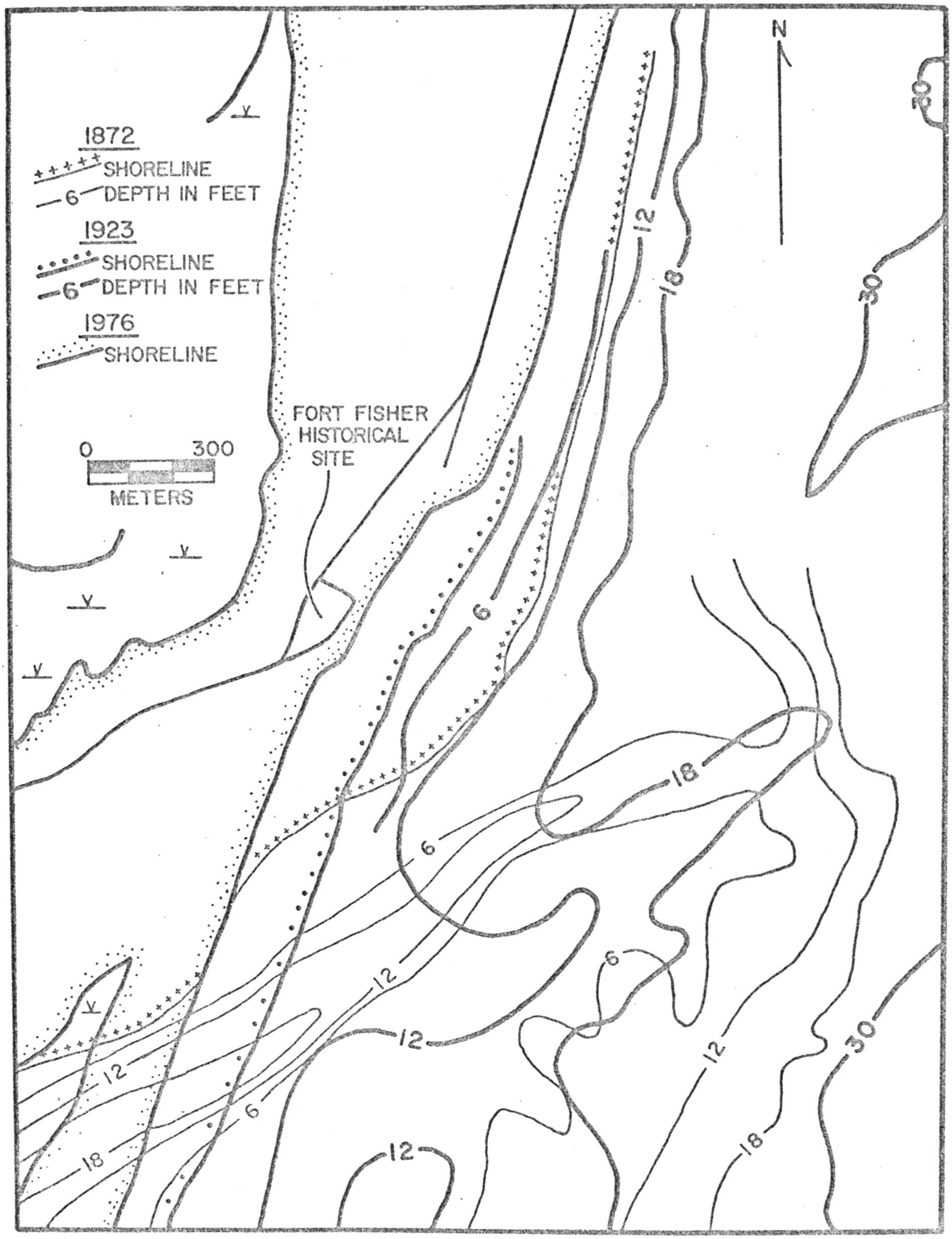

Figure 40. Comparison of the 1872 and 1923 bathymetric surveys (see Methods of Study for map references).

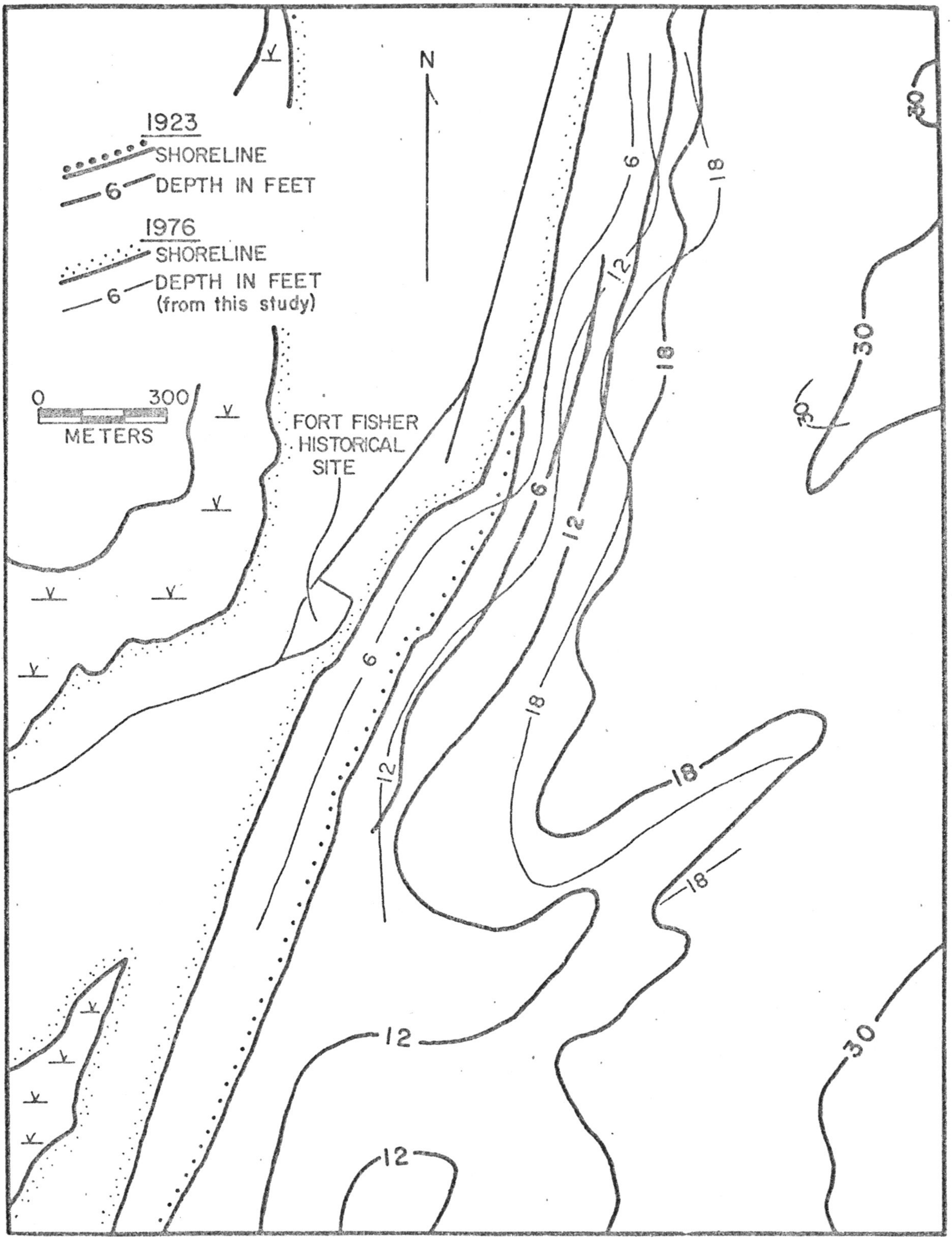

Figure 41. Comparison of the 1923 and 1976 bathymetric surveys (see Methods of Study for map references).

the construction of the New Inlet Dam. The northeast trending shoal, defined by the 12 and 18 foot depth contours of the 1923 survey, appears to be a product of the New Inlet ebb-tide delta (Figure 40). Also, significant removal of nearshore sand occurred directly seaward of the Historic Site. The eroded sediment does not appear to have been deposited further offshore, but rather was probably transported southward to the rapidly growing barrier spit system. The reworking and removal of sediment occurred as the shoreline adjusted to a new energy regime created by the southward migration of New Inlet. The removal of the broad sand body seaward of the Historic Site left the previously accreting shoreline exposed to higher energy conditions (Figure 40). Thus, the erosion of inlet-related nearshore sediments in response to a new energy regime created by the construction of the New Inlet Dam may have been a significant erosional factor.

Little change in bathymetry occurred between the 1923 and 1976 surveys. Bottom contours and the shoreline itself generally moved shoreward. The northeast trending shoal appears to have moved southeast during this period, possibly in response to reworking by the net southward longshore drift (Figure 41).

SHORELINE PROTECTION MEASURES

In 1931, the U. S. Army Corps of Engineers proposed the construction of three groins in front of the Historic Site, however they were never constructed. Thus, no shoreline protection measures were implemented prior to 1955. At this time, the State of North Carolina built two rubble mound groins seaward of the Historic Site (U. S. Army Corps of Engineers, 1974) (Figure 42). The two groins have since settled into the sand and are now only exposed at low tide. In 1959, a rubble revetment, 3.6 to 4.2 m in height, was constructed along 210 m of the eroding Historic Site shoreline (U. S. Army Corps of Engineers, 1974) (Figure 42). This revetment consisted of large pieces of concrete and brickwork. The majority of the 1959 revetment is still in place.

During the period between 1959 and 1965, the bluffs on the north and south flanks of the 1959 revetment eroded severely. Thus, additional rubble was added to the eroding banks on both ends of the revetment in 1965 (Figure 42). Also, 11,500 m^3 of sand was used to replenish 210 m of beach north of the revetment (U. S. Army Corps of Engineers, 1974). By 1967, the sand fill had been severely eroded and an additional 11,500 m^3 of sand was added to the remaining fill. Nearly all the beach replenishment sands had been eroded by 1969 (U. S. Army Corps of Engineers, 1974). An emergency limestone boulder revetment (Figure 43) was constructed

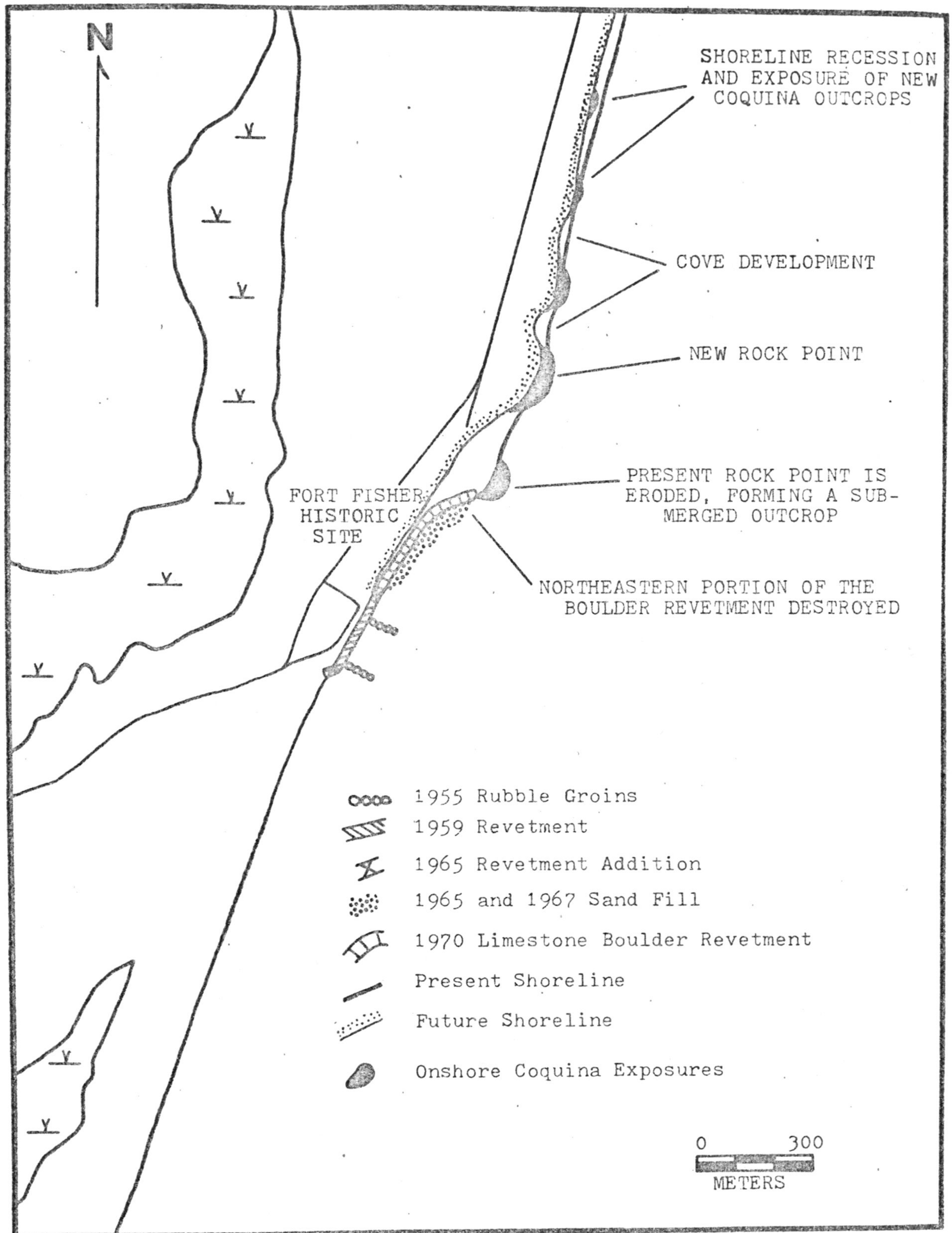

Figure 42. Previous shoreline protection measures and predicted future shoreline movements.

Figure 43. View, directed north, of limestone boulder revetment in 1970. Coquina rock point in upper right of photograph. (From U. S. Army Corps of Engineers, 1974).

Figure 44. View, directed south, of the eroding bluffs and ineffective limestone boulder revetment along the Historic Site shoreline. Taken in 1977.

around the northwestern perimeter of the cove in 1970. This revetment, consisting of boulders ranging up to 1.2 m in diameter, has been partially destroyed in places by settlement of the boulders during storm conditions. The boulders are undermined by the swash from the breaking waves and the fresh water drainage off the adjacent land areas. This causes the rocks to gradually sink into the forebeach sand. Some of the boulders may actually be moved during the highest storm energies. Erosion is presently occurring along the bluff behind the revetment as a result of wave swash undercutting during storm tides and slope wash from fresh water surface runoff (Figure 44). The establishment and growth of large gullies which dissect the bluffs is an important erosional process along the shoreline fronting the Fort Fisher Historic Site.

FUTURE SHORELINE CHANGES

If the Fort Fisher shoreline is left as it is today, it is expected that the processes discussed earlier will continue to operate. New coquina outcrops will become exposed in a northerly direction along the strandplain beach (Figure 42). The new outcrops will accelerate the present rate of erosion in areas adjacent to the rocks. Small erosional coves will form between the coquina points. The artificial dune line directly behind the eroding bluffs north of the point will eventually be destroyed. Severe erosion will continue in the Historic Site cove area for a period of time. The northeastern end of the limestone revetment will be destroyed (Figure 42). Erosion of the revetment, the bluff directly landward of the coquina point, and the coquina point itself will form a new shoreline that will be in greater equilibrium with the present energy regime and naturally occurring shoreline processes. This situation should allow more littoral sediment to reach the older and southernmost portion of the cove beach, thus possibly decreasing the erosion rates within the cove.

The U. S. Army Corps of Engineers (1974) has proposed an erosion control program for the Fort Fisher shoreline consisting of a new bluff revetment, beach fill, groin system, and periodic beach nourishment (Figure 45). The project cost was estimated at approximately $5,000,000 in 1974 (U.S.

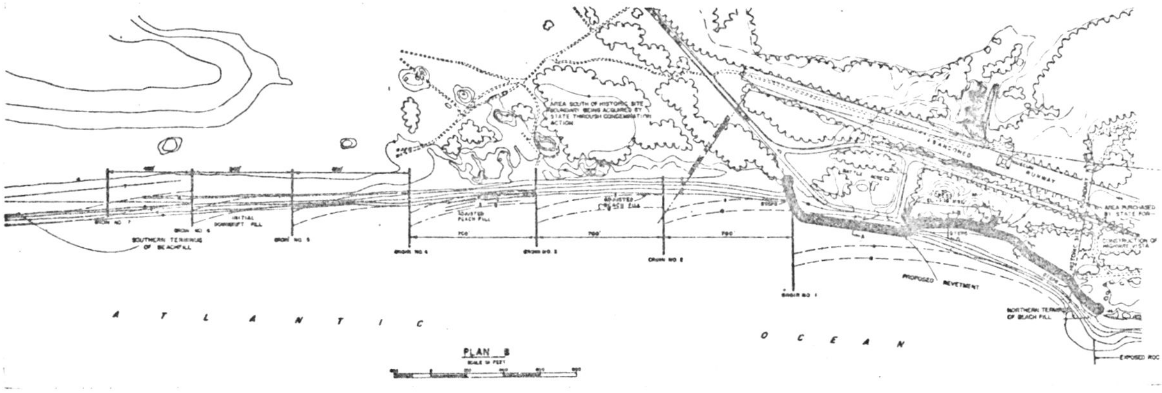

Figure 45. Proposed erosion control measures for the Fort Fisher shoreline (from U. S. Army Corps of Engineers, 1974).

Army Corps of Engineers, 1974). Beach fill will be dredged from channels within the Basin area. Beach nourishment will be implemented at 5 year intervals.

If this proposal is carried out, erosion rates within the cove and south of the Historic Site will be substantially decreased. However, the U. S. Army Corps of Engineers proposal does not include any protective measures for the strandplain shoreline north of the cove. If shoreline recession rates accelerate or even continue at their present rate along the northern strandplain beach, it is conceivable that the proposed concrete revetment could become a concrete "point" itself as the shoreline north of the cove recedes landward of the revetment. Thus, the strandplain bluffs north of the cove may also have to be protected eventually.

H I S T O R I C A L   G E O L O G Y

The main objective of this study is to relate the geology of the Fort Fisher area to the historical and present shoreline processes. While working with the geology of the Fort Fisher area, I have developed some ideas which may contribute to the further understanding of the historical geology of the lower Cape Fear Peninsula. The ideas presented herin are theories based largely upon my field observations.

RELATED RELICT DEPOSITS OUTSIDE OF THE FORT FISHER AREA

Snow's Cut

Two extensive coquina outcrops occur in Snow's Cut, an artificial cut across the Cape Fear Peninsula for the Intracoastal Waterway (Figure 46). The coquina, exposed on both sides of Snow's Cut, is most extensive on the south side of the Waterway where the rock is exposed for a distance of 101 m. Up to 6.7 m of rock is exposed and is overlain by a thin mantle of weathered coquina and surficial sands. Gravelly quartz sands are exposed on the east flank of the outcrop. On the western flank, fine to medium quartz sands are exposed.

Two distinct coquina facies occur in the Snow's Cut exposure. The lower facies consists of well indurated sandy coquina identical to the coquina at Fort Fisher. The rock is highly cross-stratified with apparent dips of 18° to 25°. Gently dipping shell and pebble lag beds are oriented

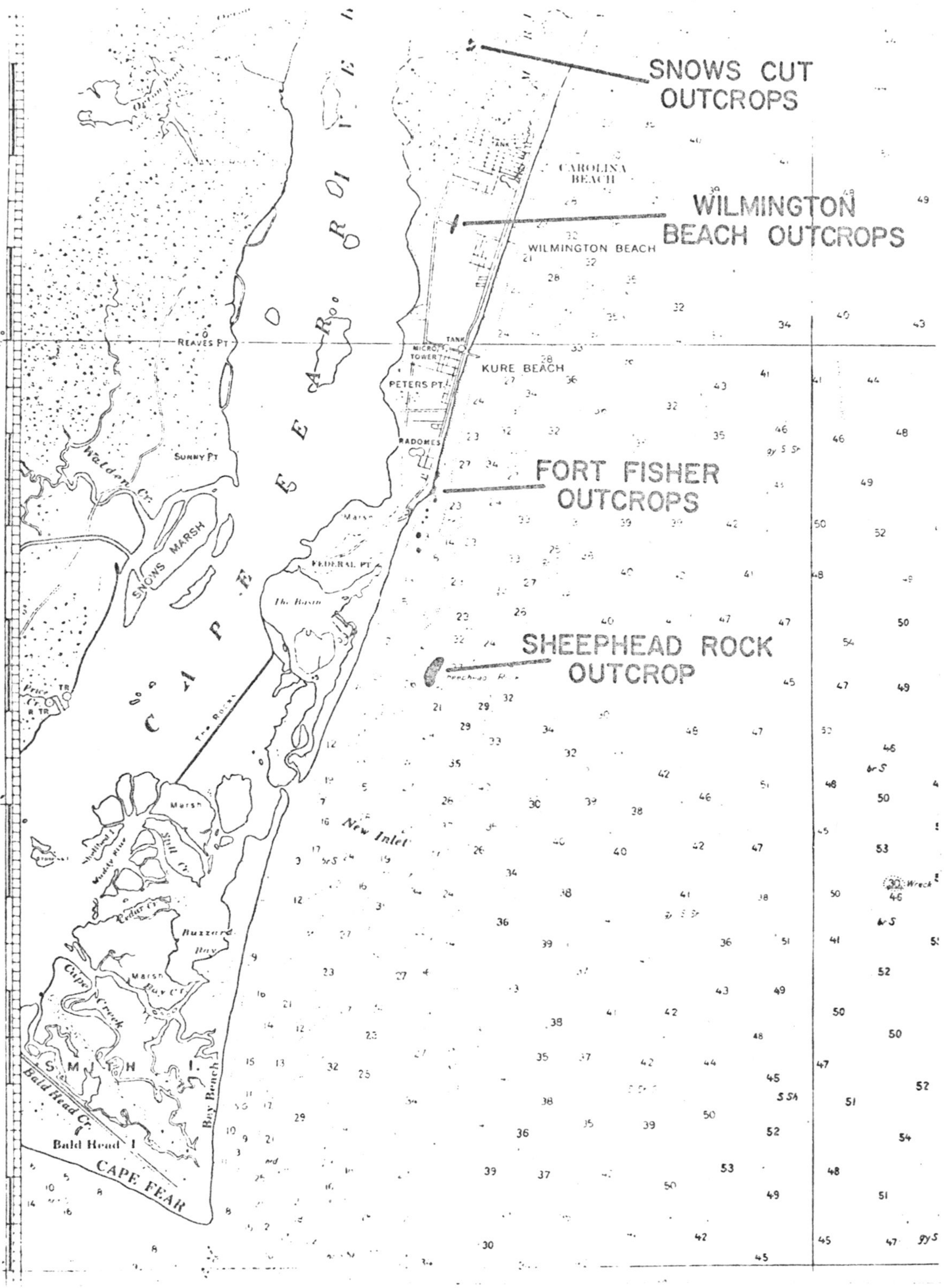

Figure 46. Locations of coquina outcrops in the Cape Fear Peninsula area (U. S. Coast and Geodetic Survey, Chart 11539).

horizontally in both convex and concave upward positions with convex upward dominating.

The upper facies is 2.4 to 3 m thick and consists of semiconsolidated to unconsolidated coquina. The acid soluble content of the rocks in this facies is approximately 50% by weight. The acid insoluble fraction consists of poorly sorted, subrounded, granular coarse quartz sand. Cross-stratification in the unconsolidated facies is similar to, but not as prominent, as the lower facies. Scattered, large vertical pothole depressions extend downward through the upper facies and into the lower facies. These depressions are smooth sided and circular with diameters up to 60 cm and depths up to 3 m. The "potholes" may be hollow or partially filled with yellowish orange granular medium quartz sand. These depressions are believed to be solutional in origin (Riggs, personal communication). No gravels of significant size can found within the base of the holes. Remnant pinnacles of consolidated coquina, surrounded by yellowish orange sands, occur where these solutional features are abundant.

The fauna at Snow's Cut consists mostly of abraded molluscan whole shells and fragments. No species are in life position. Fallaw (1973) described the molluscan fauna as a mixed assemblage of nearshore marine and estuarine species. The dominant marine fossils are Donax variabilis, Mercenaria campechiensis, Lunarca ovalis, and Noetia ponderosa.

The estuarine species include _Rangia cuneata_, _Crassostrea virginica_, _Nassarius obsoletus_, _Mercenaria mercenaria_, and _Tagelelus gibbus_. _Mulina lateralis_ and _Nassarius trivittatus_ are both sound and ocean fossils. Foraminifera are mainly large, thick walled, marine and estuarine types (Fallaw, 1973).

Wilmington Beach

Coquina is exposed in a drainage ditch west of Wilmington Beach (Figure 46). The coquina exposure is 224 m long and approximately 1.5 m in height. The base is unexposed. The outcrop surface has been obliterated by construction equipment and no internal structures can be discerned. The rock lithology is identical to the lower facies at Snow's Cut and the Fort Fisher outcrops. The coquina is overlain by 0.9 m of brown, humate-rich, granular medium quartz sand. These sands are overlain by approximately 1 m of ditch spoil.

Other Exposures

Other relict exposures include the gravelly sands exposed in the banks of Snow's Cut and within the eroding cliffs on the east bank of the Cape Fear River. The deposits are generally granular medium to coarse quartz sands with common pebble laminae. Color ranges from white to yellowish orange to dark brown depending upon the amount of iron staining and humate present. These sands are similar in composition and texture to Unit I Erosional Bluff Sands outcropping on the strandplain beach at Fort Fisher. A similar beach outcrop has been reported by Wells (1944) at Kure Beach.

ORIGIN OF COQUINA DEPOSITS ON THE CAPE FEAR PENINSULA

Numerous depositional environments have been postulated for the coquina of the Cape Fear Peninsula. Wells (1944) suggested the rock was deposited as a mass of sand and shells adjacent to a regressive sea. Dubar and Johnson (1964) felt that the rock was deposited by longshore currents within a nearshore environment. White (1966) proposed that shoals, such as the Cape Fear Frying Pan Shoals, would be favorable places for shell hash to accumulate. Fallaw (1973) suggested that the cross-stratification and fossil assemblages are evidence of inlet deposition or possibly offshore shoal deposition. Mixon and Pilkey (1976) have sampled similar submerged coquina exposures on the shelf southwest of Cape Lookout, North Carolina. They feel that a beach or near beach environment of deposition is indicated by the coarse grain size, high degree of grain rounding, and fossil assemblage. Thus, the proposed depositional environments can be summarized into three basic categories: inlets, cape shoals, and forebeach-nearshore areas.

Hubbard and Barwis (1977) characterized inlet deposition by the following features: 1) bidirectional trough cross-stratification interbedded with channel lag deposits, 2) a mixed marine-estuarine fossil assemblage, and 3) planar stratified gravelly sands deposited in associated beach or ebbtidal delta overlying the trough cross-bedding. Such stratigraphic sequences could be produced by migrating inlets within a barrier system.

Deposition in a prograding forebeach-nearshore beach system is also characterized by trough cross-stratification formed by high energy wave conditions (Clifton _et al_, 1971). They report that under the influence of longshore currents, the trough axes will be oriented in the direction of longshore current. Both landward and seaward dipping trough cross-stratification may also be found in the nearshore. The seaward dips are related to rip currents, while the landward dips result from migrating megaripples (Clifton _et al_, 1971). In a prograding shoreline with substantial sediment input, these features could be preserved. A mixed assemblage of molluscs may have resulted from eroding deposits of relict estuarine sediments within the nearshore bottom or proximity to inlet systems. Such mixed marine-estuarine shell assemblages occur along the Fort Fisher shoreline today.

Cape shoal environments are characterized by high energy conditions in which multidirectional currents occur. Hunt _et al._ (1977) report that megaripples are formed by both north and south flowing currents in the Diamond Shoals area off Cape Hatteras, North Carolina. Clifton _et al._ (1971) and Harms _et al_.(1975) report that high angle trough cross-stratification is produced by migrating megaripples and dune sand bodies. A mixed marine-estuarine fossil assemblage might be expected to occur in a river influenced cape shoal environment such as the Cape Fear Frying Pan Shoals system. The granular sands which conformably overlie the coquina are not significantly cross-stratified and thus represent a different energy regime. Possibly, these sands were deposited in a fluvial environment as the Cape Fear River extended seaward as a result of regressing sea level. The locations and widths of emerged and submerged coquina outcrops on the Cape Fear Peninsula and offshore areas suggest that the coquina is a narrow linear body which trends approximately N 3° E. This orientation may be related to a pre-Holocene position of the relict Frying Pan Shoals. The occurrence of coquina in cuspate-foreland-shoal systems is too common to be ignored. This relationship suggests that either coquina could form in cape-shoal environments or that cape structures could influence the preservation of coquina deposits.

The stratigraphic character of the coquina cement may also shed some light upon the environment of deposition. The coquina outcrop within the bluffs at Snow's Cut appears to be gradational with the granular sands east and west of the rock. The lack of cement in the flanking sediments suggests that the coquina is self-cementing as a result of greater groundwater flow through a coarser sand-shell facies enclosed within a finer grained facies. Calcium carbonate dissolved from shell material within the upper coarse facies of the coquina could have been precipitated within the lower facies of the coquina under the proper physical-chemical conditions.

Cross-stratification measurements at the Fort Fisher beach outcrops indicate deposition occurred as a result of northwest and northeast flowing currents. The cross-stratification evidence, when combined with the occurrence of lag deposits and a mixed marine-estuarine fossil assemblage, strongly suggests deposition in a system of migrating inlets similar in orientation and processes to the present New Inlet.

However, in light of the association of coquina with capes, I wish to propose a slightly different depositional environment. I suggest that the coquina may have been deposited in a migrating Cape Fear River mouth, which is essentially a "mega-inlet". If the Cape Fear-Frying Pan Shoals system migrated seaward in response to a regressing sea, as suggested by Hoyt and Henry (1971) and White (1966), a "mega-inlet" deposit, similar except in scale to the previously discussed inlet deposits, could be preserved within nearshore and fluvial sediments as the cuspate-foreland system migrated seaward burying the "mega-inlet" channel deposits.

Fallaw and Wheeler (1969) proposed a Late Pleistocene age of deposition for the coquina. Mixon and Pilkey (1976) also suggest a Late Pleistocene age of deposition for similar coquina samples from the Cape Lookout area. Stratigraphic relationships from this study also indicate a Late Pleistocene deposition in response to a sea level transgression-regression with cementation taking place as a result of emergence during a subsequent pre-Holocene low sea level stand.

SUMMARY AND CONCLUSIONS

1) The Fort Fisher area is a complex combination of nearshore, strandplain, barrier island, and estuarine systems. Relict geologic units have been, and are being, reworked by the coastal processes operating on the nearshore shelf and the strandplain environments to produce the barrier island and estuarine features located south of the study area. These coastal processes are naturally occurring processes which have been modified by man.

2) Relict geologic units occur within the strandplain beach and in the offshore area. Unconsolidated sand units crop out in the eroding bluffs associated with the strandplain beach. Coquina forms platform-like outcrops within the strandplain forebeach. Submerged coquina crops out adjacent to, and south of, the emerged coquina deposits. Relict gravel and coarse sand units also occur in the offshore area.

3) Modern sediments within the forebeach-nearshore study area consist of fine to very coarse quartz sands mixed with varying amounts of coquina fragments, quartz pebbles, and whole and fragmented shells. Organic-rich mud also occurs as thin blanket-like deposits in depressions at depths of 7 m (23 ft) to 9.1 m (30 ft).

4) The eroding coquina and strandplain bluff sands are an important source of modern sediment to the Fort Fisher forebeach-nearshore system.

5) A progression of shoreline development, related to dominantly erosional processes, occurs along the Fort Fisher strandplain shoreline. Stationary coquina outcrops produce a disequilibrium condition within the forebeach. The disequilibrium condition results in increased shoreline recession along the beaches adjacent to the rock outcrops. The strandplain bluff is undercut and eroded by wave swash and rainfall runoff. When these sediments are moved offshore during storms, the extensive coquina outcrops act as a barrier preventing their landward transport during low energy periods. The onshore rocks also extend seaward into the nearshore area and act as low groins; this produces a net sediment loss to the downdrift beach. As a result of this sediment deficiency, a steep forebeach profile develops associated with rapidly eroding bluffs. This results in the development of a rapidly receding cove structure. The upper portions of the coquina are continuously eroded by wave impact and abrasion, ultimately becoming totally submerged rock outcrops.

6) The Fort Fisher barrier system is dominated by spit extension processes associated with the rapid southward migrations of New Inlet that began in response to the construction of the New Inlet Dam. Inlet development within the northern portion of the barrier and subsequent southward migration has been an important reoccurring process of the barrier beach.

7) Since 1852, the Fort Fisher shoreline has experienced both dramatic accretion and erosion. Accretion occurred from 1852 to 1865. This was probably related to the development of a major ebb tide delta in conjunction with a fairly stable New Inlet. Erosion occurred during the period 1865 to 1923 as the once river dominated inlet system adjusted to a new energy regime created by the New Inlet Dam. Erosion has occurred since 1923 in response to the sequential exposure of coquina outcrops within the strandplain forebeach and the resulting disequilibrium. The most dramatic erosion has taken place in the sediment starved coves adjacent to the coquina headlands.

8) Coquina-related erosional processes will continue to operate in the future. Shoreline recession rates will accelerate along the northern strandplain beach as new portions of the linear rock unit become exposed.

9) The entire strandplain beach and coquina outcrop system should be considered as a total inter-related system in planning any future shoreline protection programs.

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APPENDIX

Sample No.	Mean Grain Size (phi)	Sorting (phi)	Gravel (%)	Sand (%)	Mud (%)	Shell (%)	Coquina (%)
1	Organic-rich Mud						
2	Organic-rich Mud						
3	2.60	1.27	2.0	89.8	8.20	9.4	0
4	2.23	0.88	0.8	97.4	1.80	5.6	0
5	0.22	1.12	14.5	85.5	0	6.3	9.8
6	2.38	0.61	0.4	99.3	0.20	3.1	0
7	1.71	0.87	4.8	95.2	0.04	10.0	0
8	0.73	1.23	10.8	89.2	0	21.4	0
9	-0.30	1.41	31.3	68.6	0.05	50.6	4.0
10	0.56	1.16	9.8	91.2	0	2.3	3.5
11	1.02	1.41	13.0	87.0	0.10	22.1	0
12	Organic-rich Mud						
13	2.18	1.16	4.6	91.7	3.70	9.9	0.1
14	1.44	1.40	9.1	90.4	0.40	2.1	15.0
15	0.94	1.16	9.2	90.8	0	3.6	1.7
16	Organic-rich Mud						
17	Organic-rich Mud						
18	0.98	1.12	9.2	90.8	0.06	23.0	0.4
19	-0.43	1.04	29.5	70.4	0.16	18.0	19.6
20	1.94	0.51	0	100.0	0	0.1	0.1
21	0.03	0.62	5.9	94.1	0	2.9	0
22	Organic-rich Mud						
23	1.55	0.96	3.8	96.1	0.15	10.6	0.7
24	1.30	2.05	18.0	80.2	1.80	6.0	19.8
25	-0.12	1.94	32.8	59.6	7.60	35.7	0
26	Organic-rich Mud						
27	0.43	1.23	15.7	84.3	0.07	27.3	0.1
28	2.87	0.57	0.5	96.8	2.70	4.4	0.4
29	0.66	1.34	13.7	86.2	0.03	4.4	7.7
30	1.41	0.51	1.6	98.4	0	6.1	0
31	-0.59	1.34	40.7	59.3	0	44.0	3.0
32	-0.13	1.64	26.4	73.6	0.04	31.6	0.4
33	Coquina exposure						
34	1.33	0.92	1.0	99.0	0	1.0	0.1
35	2.13	0.63	0.9	99.0	0.02	2.6	0
36	0.20	1.15	17.5	82.5	0	29.5	0
37	0.40	0.83	5.2	94.8	0	20.2	0
38	2.20	0.72	0.4	98.0	1.60	2.5	0.2
39	0.57	1.26	10.7	89.3	0	6.5	2.1